FINAL

Final Status Survey Report: Characterization and Final Status Survey Radioactive Materials Handling Facility Perimeter

Santa Susana Field Laboratory

Ventura County, California

Contract Number R58KXZ05-09-2532

Prepared for:

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LIST OF ACRONYMS, ABBREVIATIONS, AND UNITS OF MEASUREMENT

Ac	actinium (e.g., ^{228}Ac)
Am	americium (e.g., ^{241}Am)
ARARs	applicable or relevant and appropriate requirements
Bi	bismuth (e.g., ^{214}Bi)
Bicron	Bicron Radiation Measurement Products
bgs	below ground surface
CABRERA	Cabrera Services, Inc.
Ci	curie
cm	centimeter
cm^2	square centimeter
Co	cobalt (e.g., ^{60}Co)
cpm	counts per minute
Cs	cesium (e.g., ^{137}Cs)
DCGL	derived concentration guideline level
DHS	California Department of Health Services
DOE	U. S. Department of Energy
dpm	cisintegrations per minute
DQOs	Data Quality Objectives
EDA	Exploratory Data Analysis
EMC	Elevated Measurement Concentration
EPA	U. S. Environmental Protection Agency
ETEC	Energy Technology Engineering Center
Eu	europium (e.g., ^{152}Eu)
Fe	iron (e.g., ^{55}Fe)
ft^2	square feet
GIS	Geographical Information System
GM	Geiger Muller
GPS	global positioning system
H	hydrogen (e.g., ^{3}H)
ID	identification
K	potassium (e.g., ^{40}K)

LCS	laboratory control sample
m	meter
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	minimum detectable concentration
Mn	manganese (e.g., ^{54}Mn)
Na	sodium (e.g., ^{22}Na)
NAD	North American Datum
NaI	sodium iodide
NELAP	National Environmental Laboratory Accreditation Program
Ni	nickel (e.g., ^{59}Ni)
NIST	National Institute of Standards and Technology
NRC	Nuclear Regulatory Commission
pCi/g	picocurie per gram
Pu	plutonium (e.g., ^{238}Pu)
QA	Quality Assurance
QC	Quality Control
Ra	radium (e.g., ^{226}Ra)
RCRA	Resource Conservation and Recovery Act
RESRAD	Residual Radiation (Environmental Analysis)
RMDF	Radioactive Materials Disposal Facility
RMHF	Radioactive Materials Handling Facility
RPD	relative percent difference
Sr	strontium (e.g., ^{90}Sr)
SSFL	Santa Susana Field Laboratory
Th	thorium (e.g., ^{232}Th)
U	uranium (e.g., ^{233}U)
U.S.	United States of America
U.S.C.	Unites States Code
μR/hr	microroentgen per hour

EXECUTIVE SUMMARY

This report presents the results of the characterization and final status survey of the perimeter of the Radioactive Materials Handling Facility (RMHF) at the Santa Susana Field Laboratory (SSFL) in Ventura County, California. The report also makes recommendations based on the results of the survey. The field work was performed from September 19, 2005, to October 14, 2005, by Cabrera Services, Inc. (CABRERA) in accordance with the *Final Field Sampling Plan: Characterization and Final Status Survey, Radioactive Materials Handling Facility Perimeter* (CABRERA 2005).

The purpose of the survey was two fold. First, the survey was designed as a characterization survey to identify the presence of radioactive contamination in the surface soil [less than 0.5 ft. below ground surface (bgs)] on the perimeter of the RMHF and to define its nature and lateral extent. Second, the survey was designed to serve as a final status survey for areas where the radionuclide concentrations were found to be below their respective derived concentration guideline level (DCGL). The survey was designed in accordance with Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) guidance such that collected survey data can be used to demonstrate compliance with the release criteria for unrestricted use.

The area of interest was divided into eight survey units. Non-intrusive surface investigations, intrusive sample collection techniques, and both on-site and off-site sample analyses were performed for each survey unit. Non-intrusive gross gamma walkover measurements were performed to identify the presence of elevated levels of radioactivity. Random-start systematic samples were collected from each survey unit. Biased surface soil samples were collected where elevated radioactivity was identified and were analyzed to help define the nature and lateral extent of contamination. Where no elevated radioactivity was identified, no additional data were collected. The on-site sample analysis was performed to support real-time decision-making.

Exploratory data analysis (EDA) was performed on the off-site laboratory analysis data to identify radionuclide distribution trends and potential outliers. EDA included visual inspection of measurement results using posting plots, cumulative frequency distributions, histograms, and calculation of statistical quantities including mean, median, standard deviation, and range. The results of the EDA for individual radionuclides and survey units are presented in Appendix A. For each survey unit, the Sign test was performed for radionuclides of concern individually and using the sum of fractions calculation. The results of the statistical tests are also presented in Appendix A.

Based on the results of the survey, CABRERA recommends the release of Survey Units 1, 2, 5, 6, 7, and 8 to unrestricted use. Further investigation is needed to support the release of the radioactively contaminated area in Survey Units 3 and 4 to unrestricted use. As an alternative to meet ALARA considerations for future site use, Survey Units 3 and 4 may be remediated and resurveyed. Contingent upon the delineation of the remediated area and buffer zone, the balance of Survey Units 3 and 4 may be released to unrestricted use.

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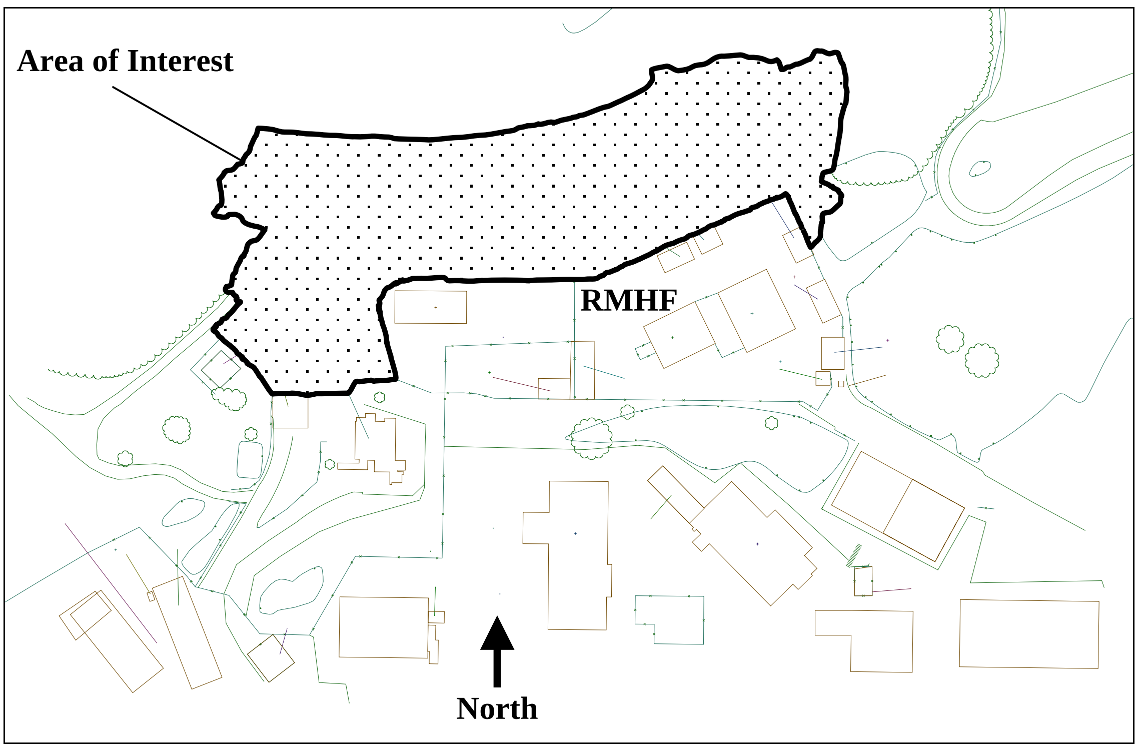
1.0 INTRODUCTION

This report presents the results of the characterization and final status survey of the perimeter of the Radioactive Materials Handling Facility (RMHF) at the Santa Susana Field Laboratory (SSFL) in Ventura County, California. The report also makes recommendations based on the results of the survey. The field work was performed from September 19, 2005, to October 14, 2005, by Cabrera Services, Inc. (CABRERA) in accordance with the *Final Field Sampling Plan: Characterization and Final Status Survey, Radioactive Materials Handling Facility Perimeter* (RMHF Perimeter FSP) (CABRERA 2005).

The RMHF is located in Area IV of the SSFL, shown in Figure 1.1. The SSFL is operated by Boeing for the United States Department of Energy (DOE). Under the authority of the Atomic Energy Act [42 United States Code (U.S.C.) 201 et seq.], DOE is responsible for establishing a comprehensive health, safety, and environmental program for managing facilities. As an Agreement State under the Atomic Energy Act, the State of California has jurisdiction over non-DOE radiological activities at the SSFL.

Figure 1.1 – SSFL Area IV



1.1 Purpose

The purpose of the survey was two fold. First, the survey was designed as a characterization survey to identify the presence of radioactive contamination in the surface soil [less than 0.5 ft. below ground surface (bgs)] on the perimeter of the RMHF and to define its nature and lateral extent. Second, the survey was designed to serve as a final status survey for areas where the radionuclide concentrations were found to be below their respective derived concentration guideline level (DCGL). The survey was designed in accordance with Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) guidance such that collected survey data could be used to demonstrate compliance with the release criteria for unrestricted use.

1.2 Scope

The scope of the survey included surface soil to a depth of 0.5 ft. below ground surface (bgs) over an area of interest on the north and west sides of the RMHF perimeter, as shown in Figure 1.1. Figure 1.2 shows the area of interest located on the north side of the RMHF perimeter. Figure 1.3 shows the area of interest on the west side of the RMHF perimeter. The southern boundary of the area is the fence on the north side of the RMHF, not including the asphalt-paved path just outside the fence. The northern boundary is the historical high water mark on the north side of the drainage channel at the bottom of the ravine north of the RMHF. The western boundary is approximately the eastern edge of the storm water catch basin just west of the RMHF, but does not include the storm water catch basin. The eastern boundary is approximately 25 feet east of Building 4688. The former leach field for Building 4021 is included in this area. No investigations of ground water, surface water, sediment, asphalt, concrete, or buildings were performed as part of the survey.

Figure 1.2 – Area of Interest on North Side of RMHF Perimeter (Looking South)

1.3 Site History

In the late 1940's, North American Aviation acquired land in the Simi Hills between the Simi and San Fernando Valleys. That land, now known as SSFL, was used primarily for the testing of rocket engines. Atomics International, a division of North American Aviation, was formed in 1955 and part of Area IV at SSFL was set aside and used for nuclear reactor development and testing. In 1984 Atomics International merged with Rocketdyne. The Boeing Company purchased Rocketdyne in 1996. Area IV of the SSFL is used for DOE-sponsored activities. Boeing, the National Aeronautics and Space Administration (NASA), and the Department of Defense have used the balance of the SSFL for rocket and laser testing.

Figure 1.3 – Area of Interest on West Side of RMHF Perimeter (Looking Southwest)

Activities in Area IV started in the mid 1950s: until 1964 these activities were primarily related to sodium-cooled nuclear power plant development and development of space power systems with sodium and potassium as coolants. The Energy Technology Engineering Center (ETEC, originally known as the Liquid Metal Engineering Center) was formed in the mid 1960s as an Atomic Energy Commission (now DOE) laboratory for the development of liquid metal heat transfer systems in support of the Liquid Metal Fast Breeder Reactor Program. Nuclear operations at Area IV included 10 nuclear research reactors, 7 critical facilities, the Hot Laboratory, the Nuclear Materials Development Facility, the RMHF, and various test and nuclear material storage areas. All nuclear operations ended in 1988. Since that time DOE-funded activities have focused on decontamination and decommissioning of the ETEC facilities.

The RMHF has been in continuous operation as a storage and handling facility for radioactive materials and waste since the late 1950s. Although nuclear operations at the SSFL ended in 1988, the RMHF has continued to support decommissioning and decontamination activities. The RMHF is a Resource Conservation and Recovery Act (RCRA) permitted facility. Operations include waste characterization, limited treatment, packaging, and temporary storage of radioactive and mixed waste materials. The RMHF is radiologically contaminated from past operations, including the storage of both new fuel and irradiated fuel (*Environmental Assessment for Cleanup and Closure of the Energy Technology Engineering Center*, Section 2.3.1.1).

The prior name for the RMHF had been the Radioactive Materials Disposal Facility (RMDF). This was a misnomer since the facility was at no time used as a disposal site for radioactive waste. It was always used as a staging facility for receipt and shipment of nuclear fuel, and later, receipt and shipment of radioactive waste. Therefore in the mid 1990s the name was changed to the Radioactive Materials Handling Facility (RMHF) to better reflect its true purpose.

1.4 Project Data Quality Objectives

The general objectives of the survey were to provide sufficient information to:

- Confirm whether one or more radionuclides of concern exceed the project action levels in areas with known or suspected radioactive contamination.
- Define the nature and lateral extent of areas (i.e., areas of surface soil) where radionuclide concentrations exceed the project action levels.
- Verify assumptions used to develop the survey design.
- Delineate areas where no radionuclide concentrations exceed the project action levels and support recommendation for unrestricted release.

Quality assurance (QA) measures were implemented throughout the project to ensure data met known and suitable data quality criteria such as precision, accuracy, representativeness, comparability, and completeness. The quality of analytical data was also controlled through the performance of quality control (QC) measurements and the calibration of field and laboratory equipment. On-site radiological measurement techniques were used based on radiological characteristics of the potential contaminants and the reasonable implementation of best available technology. The measurement analysis results were reviewed, evaluated using exploratory data analysis (EDA), and compared to the project action levels using the Sign test.

1.4.1 Step 1 – State the Problem

The problem was the potential presence of concentrations of radionuclides of concern (i.e., those resulting from DOE activities) in surface soil exceeding the project action levels. The radionuclides of concern are discussed in Section 2.3. The project action levels are discussed in Section 2.4.

1.4.2 Step 2 – Identify the Decision

The principal study question for the survey was to determine the nature and lateral extent of radioactivity in surface soil on the RMHF perimeter resulting from DOE activities. The following alternative actions resulted from resolution of the principle study question for this investigation:

- If radionuclide activity concentrations were found to be below the action levels, then no additional investigation was performed as part of the characterization survey and the area was recommended for unrestricted release.
- If radionuclide activity concentrations were found to be above the action levels, then additional data collection was performed as part of this characterization effort to define the nature and lateral extent of the surface soil radioactive contamination.

Based on the alternative actions listed above, the decision statement for the characterization and final status survey was to determine whether or not surface soil concentrations for radionuclides of concern required additional data collection to define the nature and lateral extent of the radioactivity.

1.4.3 Step 3 – Identify Inputs to the Decision

The following will be utilized to support decisions

- Radionuclides of concern (Section 2.3)
- Project action levels (Section 2.4)
- Measurement inputs (Sections 3.4, 3.5, and 4.0)

1.4.4 Step 4 – Define the Study Boundaries

The target population of interest was the radionuclide concentration in surface soil to a depth of 0.5 ft. bgs over the area of interest on the north and west sides of the RMHF perimeter. The northern boundary is the historical high water mark on the north side of the drainage channel at the bottom of the ravine north of the RMHF. The western boundary is approximately the western edge of the storm water catch basin just west of the RMHF, but does not include the storm water catch basin. The former leach field for Building 4021 is included in this area.

1.4.5 Step 5 – Develop a Decision Rule

The decision rules, given in Table 1.1, were applied. Decisions on whether to perform additional investigations were made for individual sample locations. Each measurement result was compared to the appropriate project action level to determine if additional data would be collected. Decisions were made on whether to release each of the eight survey units for unrestricted use.

Table 1.1 – Survey Decision Rules

Parameter of Interest	***IF***	***THEN***	***Comments***
Gross Gamma Walkover			
Presence of Contamination	Area with z-score greater than 3.0 is identified,	Collect a biased surface soil sample to investigate the nature of elevated radioactivity.	Z-score values greater than 3.0 are unexpected and potentially identify areas of elevated activity.
	A gross gamma result is the highest result in a survey unit,	Collect a surface soil sample to investigate the nature of elevated radioactivity.	The maximum gross gamma value potentially identifies areas of elevated activity.
Small Area of Elevated Activity – Highest and Biased Investigation			
Presence of Contamination	Gamma spectroscopy results for a surface soil sample do not exceed project action levels,	Perform no further investigation at sample location.	No additional characterization to be performed.
	Gamma spectroscopy results for a surface soil sample exceed project action levels,	Select supplemental surface soil sample location(s) farther from initial sample location.	Data collected and analyzed to define lateral extent of elevated activity.

Parameter of Interest	***IF***	***THEN***	***Comments***
Average Radionuclide Activity Concentration			
Average survey unit Radioactivity	The cesium-137 (^{137}Cs) concentration for all systematic sample results from the on-site laboratory is less than 7.15 picocuries per gram (pCi/g) in a survey unit,	Send the samples to an off-site laboratory for analysis of radionuclides of concern, and perform MARSSIM statistical tests to demonstrate if the survey unit meets the release criteria.	Survey units that pass the MARSSIM statistical tests and do not contain small areas of elevated activity demonstrate compliance with the release criteria and are recommended for unrestricted release.
	The ^{137}Cs concentration for any systematic sample results from the on-site laboratory exceeds 7.15 pCi/g in a survey unit,	Review the results of gross gamma walkover, highest, and biased results to determine if the area is uniformly contaminated or if there is a small area of elevated activity.	
	A survey unit is uniformly contaminated,	Perform additional gross gamma walkover measurements and collect additional surface soil samples to determine the lateral extent of contamination.	
	A small area of elevated activity is identified within a survey unit,	Present options for additional investigation to the Boeing project manager.	Small areas of elevated activity may exceed the DCGL values in Table 4.1 and not exceed the dose- and risk-based release criteria.
	The cobalt-60 (^{60}Co) concentration for any systematic sample results from the off-site laboratory exceed the MDC,	Present options for additional investigation to the Boeing project manager.	The presence of ^{60}Co is used as an indicator for the potential presence of hard-to-detect activation products.

1.4.6 Step 6 – Specify Limits on Decision Errors

The survey was designed as a graded approach using a combination of gross gamma walkover survey data, on-site gamma analysis, and off-site laboratory analysis of surface soil samples to manage uncertainty. Sampling uncertainty was controlled by collecting additional samples from the area of interest. Analytical uncertainty was controlled by use of appropriate instruments, methods, techniques, and quality control (QC). Minimum detectable concentrations (MDCs) for individual radionuclides using specific analytical methods were established. Uncertainty in the decision to release areas for unrestricted use was controlled by the number of data points in each area and the uncertainty in the estimate of the mean radionuclide concentrations.

1.4.7 Step 7 – Optimize the Design for Obtaining Data

Sampling and analysis processes were designed to provide near real-time data during implementation of field activities. These data were evaluated (i.e., against the project action levels and by EDA) and used to refine the scope of field activities, as needed, to optimize implementation of the survey design and ensure the data quality objectives (DQOs) were met.

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2.0 RADIOLOGICAL OVERVIEW

A review of historical information, including previously collected radiological data, was performed as part of the survey design. The scope of the survey was determined based on the radioactive contamination scenarios identified. The survey design was built using on the radionuclides of concern and the release criteria which were previously established for SSFL.

2.1 Historical Information

Multiple incidents occurred in the RMHF that could have resulted in releases of radioactivity to the environment. Major events that resulted in potential releases of radioactivity, along with surveys that identified radioactivity in the environment, are summarized below. Several spills and sodium fires occurred in Building 4021, but did not result in releases to the environment.

- The Building 4021 leach field was constructed in the spring of 1959 as a sanitary sewer leach field.
- In 1961, the Area III sewage disposal system began accepting sanitary waste, making the leach field unnecessary.
- In the fall of 1962 or spring of 1963, a valve to the RMHF radioactive water processing system was inadvertently left partially open and allowed an unknown amount of radiologically contaminated water to enter the leach field.
- On May 13, 1965, the flocculation tower in the RMHF overflowed, spilling radioactive water onto equipment, the pad, and the surrounding soil.
- In January 1966 a special environmental survey was performed. Samples were collected outside the north fence of the RMHF, in the drum storage yard, and in the ravine. Gross beta-gamma activity levels ranged from 26 to 1005 pCi/g for soil, 161 to 70,680 pCi/g for vegetation, and 30 to 30,400 picocuries per liter (pCi/L) for water.
- In 1976 levels of contamination as high as 115,000 pCi/g were identified in the leach field.
- Decontamination and removal activities in the leach field occurred between 1976 and 1978. Approximately 36,250 cubic feet of contaminated soil and sludge were removed and shipped to radioactive waste disposal sites. Small amounts of radioactivity, estimated at 0.6 millicuries, remain sequestered in inaccessible recesses and three contaminated cracks in the bedrock beneath the leach field. Prior to completion of the leach field decontamination, heavy rains during January and February of 1978 caused contaminated water to leach out of the soil in the leach field. A catch basin was constructed and about 42,000 gallons of contaminated water was collected and pumped to storage tanks. Sixty-two 55-gallon drums of contaminated soil were removed from the drainage path of the water towards the site boundary. Water samples at the site boundary contained less than 300 pCi/L of gross beta activity.
- Following the remediation of the leach field in 1978, a survey was performed. Gross beta activities in soil ranged from 15 to 46 pCi/g. The maximum gamma exposure rate following backfilling the excavated leach field was 50 microroentgens per hour (μR/hr). The source of the gamma exposure readings was attributed to radioactive waste stored at the RMHF.

- A 1981 survey was performed to support decommissioning of the RMHF. Small areas of contamination were identified in soil samples collected beneath the asphalt inside the RMHF and in soil samples collected outside the fence north, south, and west of the facility. Surface soil gross beta-gamma activities ranged from 21 to 1143 pCi/g. Activities in soil collected at 12 inches below ground surface ranged from 20 to 104 pCi/g.
- In 1989, soil samples were collected from six areas surrounding the leach field. In addition, boulders located on the north slope of the leach field backfill leading down to and including the ravine were surveyed for beta radiation. One boulder in the ravine was identified with beta radiation above background, with a maximum reading of 400,000 disintegrations per minute per 100 square centimeters (dpm/100 cm^2). The ^{137}Cs concentrations in soil ranged from 0 to 7 pCi/g, with an average of 2.18 pCi/g and a standard deviation of 2.55 pCi/g. Uranium-238 (^{238}U) and thorium-232 (^{232}Th) concentrations were similar to background (i.e., approximately 1 pCi/g). Visual inspection and radiation survey and sampling during this project verified that this contamination had been remediated at the time.
- On October 3, 1997, four concrete blocks in the parking lot were found to have beta contamination ranging from 100 to 800 counts per minute (cpm).
- In 2000, a survey of the RMHF and surrounding areas was conducted. Twenty-three soil samples collected south, west, and north of the perimeter fence were analyzed for ^{137}Cs. Thirteen samples reported concentrations less than 1 pCi/g, six samples reported concentrations between 1 and 10 pCi/g, and 4 samples reported concentrations between 10 and 53 pCi/g. Six samples were collected from the leach field area and analyzed for ^{137}Cs. Five of the samples reported concentrations similar to background (i.e., approximately 0.2 pCi/g), and one sample reported a concentration of 1.2 pCi/g.
- In 2003, a localized area of elevated radioactivity outside the south fence of the RMHF was investigated. Concentrations of ^{137}Cs ranged from non-detectable to 124 pCi/g, with an average concentration of 27 pCi/g. An area 12 feet by 50 feet by 2 feet was excavated. Six confirmation samples were collected following excavation with ^{137}Cs concentrations ranging from 1.65 to 7.08 pCi/g with an average of 3.75 pCi/g.

2.2 Radioactive Contamination Scenarios

The area of interest is located down slope from the RMHF. Leaks and spills are known to have released radioactive contamination to the leach field. Before remediation was complete, radioactive contamination may have leached out of the soils in the leach field. Runoff from the RMHF is also a plausible radioactive contamination scenario.

2.3 Radionuclides of Concern

Boeing and DOE identified radionuclides of concern for the SSFL in the *Approved Sitewide Release Criteria for Remediation of Radiological Facilities at the SSFL* (Boeing 1998). Table 2.1 lists the radionuclides of concern for the SSFL. The radionuclide ^{60}Co is used as an indicator for the presence of hard-to-detect activation products, specifically tritium (^{3}H), iron-55 (^{55}Fe), nickel-59 (^{59}Ni), and nickel-63 (^{63}Ni). Potassium-40 (^{40}K), listed as a radionuclide of concern, is more suitably described as a radionuclide indicator of interest. The consistent background concentration of ^{40}K in soil makes it useful as a benchmark for laboratory analytical results - the manner in which it is used was used in this report.

Table 2.1 - Radionuclides of Concern

Transuranic	***Fission***	***Source/Uranium***	***Natural***	***Activation***
^{238}Pu	^{90}Sr	^{228}Th	^{40}K	^{3}H
^{239}Pu	^{134}Cs	^{232}Th	^{226}Ra	^{22}Na
^{240}Pu	^{137}Cs	^{234}U		^{54}Mn
^{241}Pu		^{235}U		^{55}Fe
^{242}Pu		^{238}U		^{59}Ni
^{241}Am				^{60}Co
				^{63}Ni
				^{152}Eu
				^{154}Eu

2.4 Project Action Levels

Gross gamma walkover survey data and the results of on-site and off-site laboratory analysis of surface soil samples were compared to project action levels. The project action levels determined whether or not surface soil concentrations for radionuclides of concern required additional data collection to define the nature and lateral extent of the radioactivity.

The project action level for the gross gamma walkover survey data was primarily based on statistical probability and used contours of z-scores (number of standard deviations from the mean). Since 0.135% of normally distributed data are expected to exceed a z-score of 3.0, a z-score greater than 3.0 was used as an indicator for investigating areas with radioactivity potentially exceeding one or more project action levels for surface soil.

The project action levels for surface soil are based on DCGLs which have been approved for use at the SSFL. The DCGLs, given in Table 2.2, are described in detail in *Approved Sitewide Release Criteria for Remediation of Radiological Facilities at the SSFL* (Boeing 1998).

Surface soil sample results analyzed by the on-site laboratory were compared to a project action level of 7.15 pCi/g ^{137}Cs. This value is the DCGL for ^{137}Cs modified to account for the other hard-to-detect or less abundant radionuclides of concern. It was calculated using the radionuclide-specific DCGL values in Table 2.2 based on the guidance in Appendix I of MARSSIM.

The radionuclide-specific DCGLs in Table 2.2 were used as the project action levels for surface soil sample results analyzed by the off-site laboratory.

Table 2.2 - DCGLs

Radio-nuclide	*DCGL (pCi/g)*	*Radionuclide/ Surrogate ^{137}Cs Ratio*[e]	*Radio-nuclide*	*DCGL (pCi/g)*	*Radionuclide/ Surrogate ^{137}Cs Ratio*[e]
^{241}Am	5.44[a]	0.003	^{240}Pu[d]	33.9[a]	0.007
^{60}Co	1.94[a]	0.048	^{241}Pu	230[a]	0.012
^{134}Cs	3.33[a]	---	^{242}Pu	35.5[a]	---
^{137}Cs	9.20[a]	1.000	^{226}Ra	5.0[b]	---
^{152}Eu	4.51[a]	---	^{90}Sr	36[a]	0.189
^{154}Eu	4.11[a]	---	^{228}Th	5.0[b]	0.00005
^{40}K[f]	27.6[a]	---	^{232}Th	5.0[b]	0.00003
^{54}Mn	6.11[a]	---	^{234}U	30[c]	0.003
^{22}Na	2.31[a]	---	^{235}U	30[c]	0.0002
^{238}Pu	37.2[a]	0.001	^{238}U	35[c]	0.001
^{239}Pu[d]	33.9[a]	0.012			

Notes:

a RESRAD calculations assuming residential future use scenario.

b DOE 5400.5 limits for first 15 cm of soil depth.

c Disposal or On-site Storage of Thorium or Uranium Wastes from Past Operations (NRC 1981).

d Assumes 63% ^{239}Pu and 37% ^{240}Pu.

e Radionuclide/surrogate ratios were provided by Boeing to calculate the modified ^{137}Cs DCGL.

f Radionuclide used as indicator of interest; DCGL not applied quantitatively.

3.0 SUMMARY OF SURVEY ACTIVITIES

The area of interest was divided into eight survey units. A gross gamma walkover survey was performed and surface soil samples were collected and analyzed. Based on the results, the decision rules were applied and additional sampling was performed as required by decision rule.

3.1 Survey Units

The area of interest is approximately 176,000 square feet in size. It includes impacted areas that have, or had prior to remediation, a potential for radioactive contamination above the DCGL, which is the definition of a MARSSIM Class 1 area. It also includes impacted areas with a low potential for radioactive contamination, which would be considered MARSSIM Class 2 or Class 3 areas. For survey design purposes, the entire area of interest was considered to be a MARSSIM Class 1 area and divided into eight survey units of approximately 22,000 square feet each. That size corresponds to the suggested area of a MARSSIM Class 1 survey unit (2,000 square meters). By limiting the survey unit size, a higher surface soil sampling density was obtained, which, in turn, reduced the size of a localized area of elevated radioactivity that could potentially escape being sampled.

The survey unit boundaries, shown in Figure 3.4, were determined based on the physical contours and the observed drainage pattern originating from the potential source location following a visual inspection of the site. A global positioning system (GPS) was used to record a sufficient number of points to define the perimeter of each survey unit.

3.2 Sampling and Analysis Methods

Gross gamma measurements were performed and surface soil samples were collected in each survey unit and analyzed to verify the presence (or confirm the absence) of radioactive contamination and its nature and lateral extent. Radiological data were collected in accordance with CABRERA radiological procedures as described in the RMHF Perimeter FSP (CABRERA 2005). As part of the QC activities, instruments were checked on a daily basis and response found to be acceptable prior to their use.

3.2.1 Gross Gamma Walkover Survey

Gross gamma walkover survey data were collected using a Ludlum Model 2221 scaler/ratemeter with a Ludlum Model 44-20 3” x 3” sodium iodide (NaI) gamma scintillation detector. The detector was suspended at a height of approximately 10 centimeters above the ground and moved in parallel lines about 0.5 meters apart at a speed of roughly 0.5 meters per second. The measurements were position correlated using the GPS. Data were automatically logged with the measurement coordinates using a Trimble TDC1 GPS. The GPS link tied survey data to spatial locations using state plane coordinates for California, Zone 5, North American Datum (NAD) 1983. The GPS was checked daily to ensure accuracy and repeatability (see Appendix C).

Much of the survey area is located on steep hillside, ranging from approximately 40 to 80 degree slopes (see Figures 1.2 and 1.3). Rock outcroppings are scattered throughout the hillside, creating areas of 90 degree (vertical) slope. A physical restraint system using rock climbing equipment, shown in Figure 3.1, was used to position the surveyor and allow him to move the detector in a controlled manner while traversing the steep terrain.

Figure 3.1 – Physical Restraint System for Slope Surveying

3.2.2 Surface Soil Sample Collection

Soil was collected over an area of 100 cm^2 to a depth of approximately 0.5 ft at each sample location. Visually identifiable non-soil components such as stones, twigs, and foreign objects were manually separated from the sampled soil. The sampled soil was mixed to homogenize it and approximately 1,500 grams of soil was collected in a 1-liter Marinelli container. The container was labeled with the sample ID, date and time of collection, and initialed by the surveyor. The sample was transferred to the on-site laboratory and counted by gamma spectroscopy. Duplicate samples were collected and the results evaluated (see Section 5.2.1).

3.2.3 Exposure Rate Measurements

Exposure rate measurements were performed at biased sample locations using a Bicron® MicroRem tissue-equivalent scintillation detector, which was checked daily (see Appendix C). The measurements were taken using the "slow" response time constant setting. The detector was positioned approximately one meter above the sample location and allowed to stabilize prior to recording the measurement. The results, shown in Table 3.1, were evaluated for health and safety issues and unusual exposure rate conditions, neither of which was determined to exist. The results are provided for informational purposes only and cannot be readily correlated with reported radionuclide concentrations at the given sample location.

3.2.4 On-site Laboratory Analysis of Surface Soil Samples

An on-site laboratory, set up and run by CABRERA personnel, was used to perform gamma spectroscopy analysis of surface soil samples. Samples were analyzed with a 15-minute count time using a Canberra Genie-2000 spectroscopy counting system with a high-purity germanium detector. QC activities include the collection of duplicate samples and daily instrument response check (see Appendix C).

Table 3.1 – Exposure Rate Measurements at Biased Sample Locations

Survey Unit	*Sample ID*	*µR/hr*	*Survey Unit*	*Sample ID*	*µR/hr*	*Survey Unit*	*Sample ID*	*µR/hr*
1	3000	9	3 (cont.)	3031	12	5	3012	10
	3001	10		3032	14		3013	11
	3002	10		3036	12		3014	11
	3028	11		3037	12		3015	11
2	3003	12		3039	9		3016	10
	3004	11		3040	10		3017	10
	3005	7	4	3008	11		3018	11
3	3006	8		3024	12		3019	10
	3007	10		3025	10		3020	10
	3009	14		3033	13	6	3021	11
	3010	11		3034	12		3030	18
	3011	14		3035	9	7	3022	11
	3026	16		3038	13	8	3023	10
	3027	10		3041	10			
	3029	17		3042	10			

3.2.5 Off-site Laboratory Analysis of Surface Soil Samples

Once counted by the on-site laboratory, the soil samples were double bagged in one-gallon Zip Lock® bags, numbered, logged, and transferred to the off-site laboratory for further analysis. The off-site laboratory, Severn Trent Laboratories (St. Louis, Missouri), is certified by a state that is authorized to provide National Environmental Laboratory Accreditation Program (NELAP) certification. A chain of custody was used to transfer custody of the sample to the off-site laboratory.

The off-site laboratory performed gamma spectroscopy analysis of the surface soil samples which, among other reasons, was used to confirm the results of on-site laboratory measurements. Samples were also analyzed for thorium, uranium, plutonium, and ^{241}Am radionuclides by alpha spectroscopy as well as radionuclide-specific ^{90}Sr by gas proportional beta and ^{241}Pu analysis by liquid scintillation. Duplicates, laboratory control samples, and blanks were performed as part of the off-site laboratory QC activities (see Section 5.2 and Appendix C).

3.3 Initial Survey Data Collection

The survey was designed to provide sufficient data to support a release decision for a MARSSIM Class 1 survey unit, or to determine if additional data were required prior to making a release decision for the survey unit. The gross gamma walkover survey was performed to identify the potential presence of small areas of radioactive contamination. Surface soil samples were collected on a random-start systematic grid to provide an estimate of the average radionuclide concentrations in each survey unit. Additional samples were collected at biased sample locations which were selected based on the results of the gross gamma walkover survey.

3.3.1 Gross Gamma Walkover Survey

The gross gamma walkover survey was performed over 100% of the accessible area in each survey unit. Inaccessible areas such as boulders, rock piles, and rock outcroppings were not surveyed and appear as data gaps in the survey coverage. Areas around and under trees and bushes and on the steep grades along the edges of the ravine were surveyed, but data gaps may have resulted due to GPS signal obstruction. In some instances, the steep grade also made it difficult for the GPS to distinguish between locations with different elevations but similar easting and northing coordinates. Figure 3.2 illustrates obstructions such as trees and boulders which the surveyors encountered.

Figure 3.2 – Gross Gamma Walkover Survey Obstructions

3.3.2 Random-Start Systematic Surface Soil Samples

Surface soil samples were collected from a minimum of 16 sample locations in each survey unit. The sample locations, shown in Figures 3.5 through 3.12 for the respective survey units, were selected based on a random-start systematic (triangular) grid. The minimum number of samples collected from each survey unit was based on the modified (or surrogate ratio) DCGL of 7.15 pCi/g ^{137}Cs and was calculated in the RMHF Perimeter FSP (Section 4.4.3) using MARSSIM guidance. The surface area of the survey unit was used to calculate the sample spacing for the triangular grid. The actual sample locations were determined in the field using the programmed GPS coordinates of the selected sample locations. A total of 134 soil samples were collected from random-start systematic locations.

3.4 Real-Time Implementation of Decision Rules

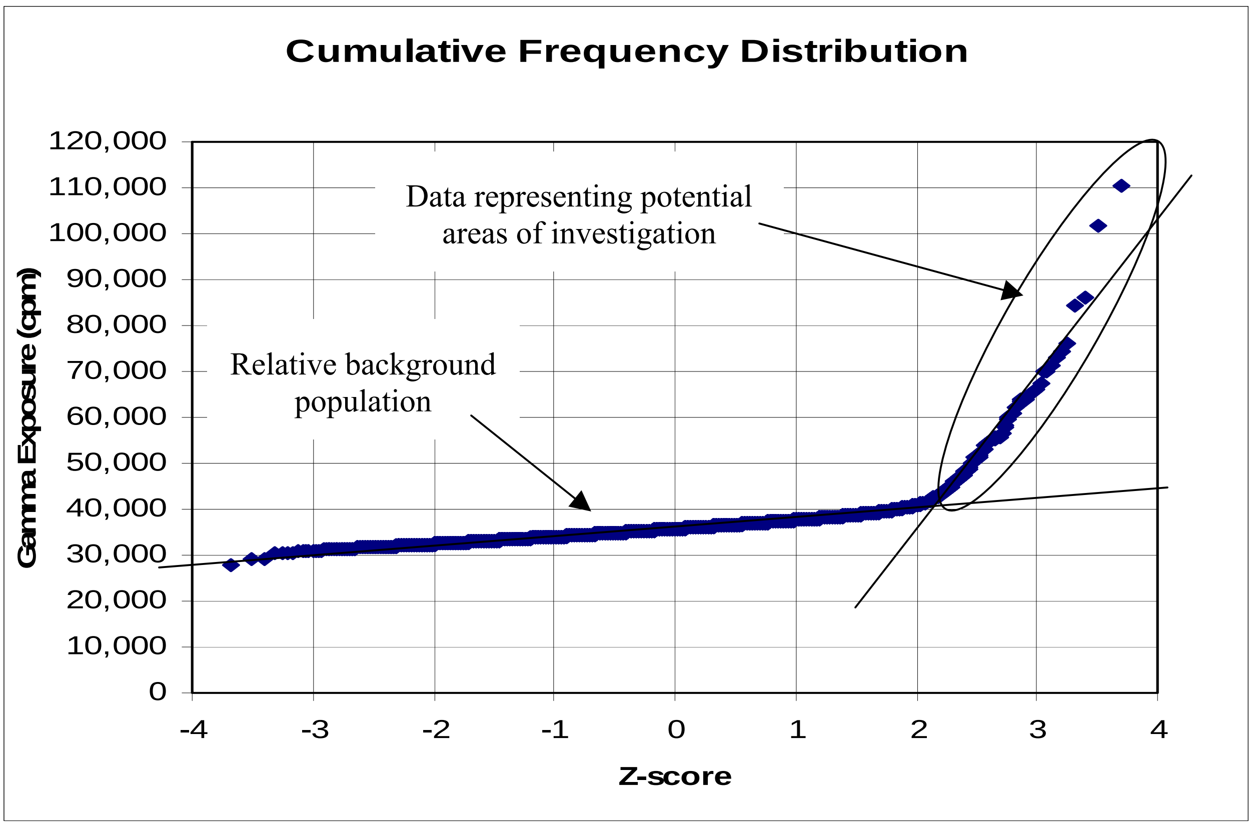
Gross gamma walkover survey data and on-site laboratory gamma spectroscopy analysis of the surface soil samples were used to provide real-time implementation of the decision rules, given in Table 1.1, to determine if additional data were required. Where potential radioactive contamination was identified, additional surface soil samples were collected and analyzed to verify its presence (or confirm its absence) and to define its nature and lateral extent. Where no potential contamination was identified, no additional data were collected.

3.4.1 Gross Gamma Walkover Survey Data Evaluation

Gross gamma walkover survey data (i.e., gross gamma count rate data logged using the GPS) were utilized to identify biased sample locations. Count rate data were evaluated by survey unit and detector, since the performance characteristics (e.g., instrument background) of each detector is slightly different. The data were evaluated with exploratory data analysis (i.e., cumulative frequency distributions, summary statistics, and z-score calculation) prior to presentation as color-coded contour plots for biased sample selection. The following description generally presents the data evaluation and biased sample selection process.

Data files were plotted on a cumulative frequency diagram (see Appendix B) to obtain information on the general shape of the data distribution. Figure 3.3 is an example of a plotted data file from Survey Unit 1. The plot reveals two distinct populations with some outliers. The flatter straight-line data represents the background count rate (i.e., non-hot spot) relative to the survey unit. The data of interest, however, are those distinctly elevated populations and individual outliers that may represent locations for further investigation.

Figure 3.3 – Example Cumulative Frequency Distribution for Survey Unit 1



Gross gamma count rate data from the relative background population were used to calculate an average and a standard deviation. The standard deviation was used to compute z-scores (number of standard deviations from the mean), which were used to create map contours based on the z-score. A z-score contour greater than 3.0 was used as an indicator for investigating areas with radioactivity potentially exceeding one or more project action levels for surface soil. Approximately 0.135% of normally distributed data are expected to exceed a z-score of 3.0.

Contour maps of the overall survey area and each individual survey unit were created once z-scores were calculated. The contouring process involves creating a regularly spaced grid and assigning values to every spot on the grid. The grid spacing and the values assigned at the grid nodes determine what the contour plot looks like. Grid node values are assigned using a weighted average based on the inverse square law, which is generally used to describe how radiation levels drop off with distance from a source. Once the grid is complete, contour lines are drawn to connect the dots with the same values.

The results of the gross gamma walkover survey in z-score contours are represented in the overall site contour map shown in Figure 3.4. Each survey unit is shown in Figures 3.5 through 3.12. The four color divisions represent various ranges of z-score values (see Section 3.4.1) with red being the highest values, followed by green, then light blue, with dark blue being the lowest values.

The contour maps were used to select biased sample locations from z-score contours greater than 3.0 (Survey Units 1 through 6). Where no contours greater than 3.0 were identified in a survey unit, a minimum of one biased sample location was selected at the point of the highest gross gamma count rate (Survey Units 7 and 8). GPS data were used to locate each biased sample location (northing and easting point) in the field. A total of 27 samples were initially collected from biased sample locations. Additional biased samples were collected later as discussed in Section 3.4.2.

Figure 3.4 – Gross Gamma Walkover Survey Coverage

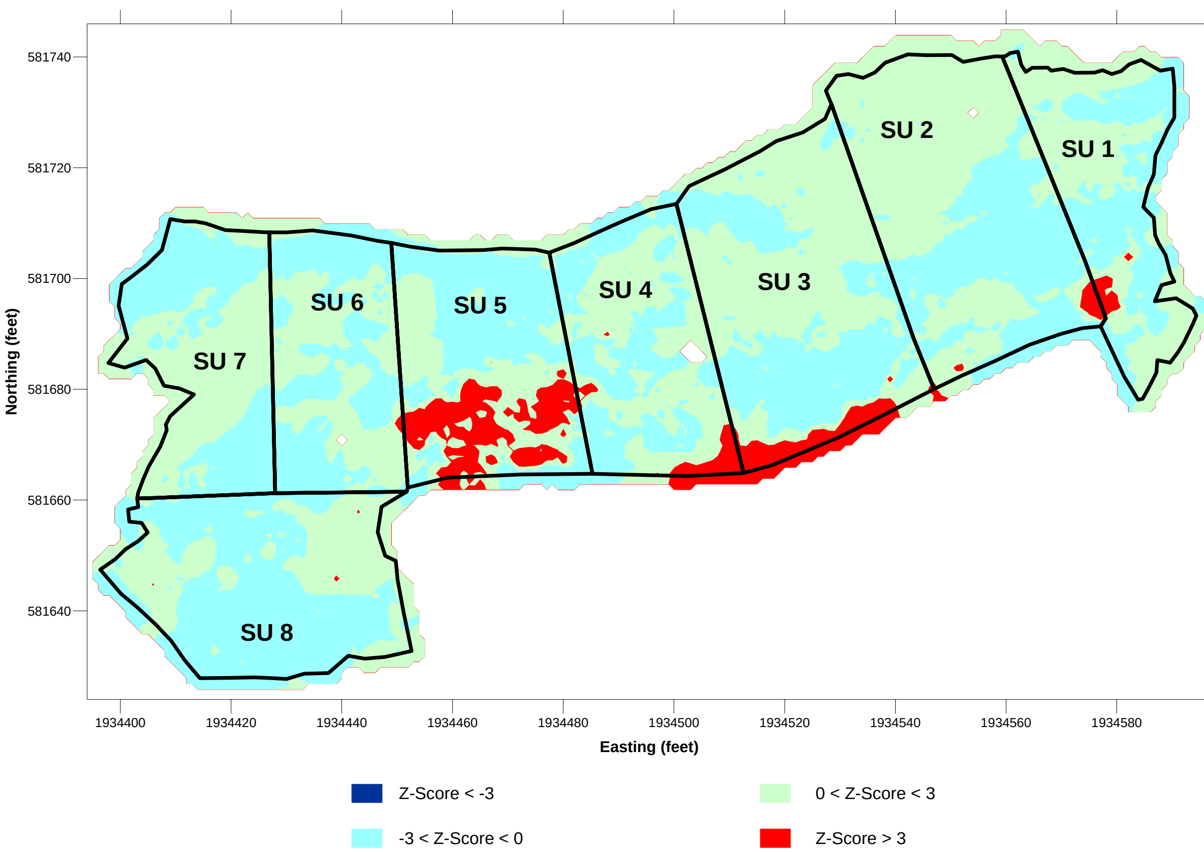


Figure 3.5 – Survey Unit 1 Z-Score Contour Map

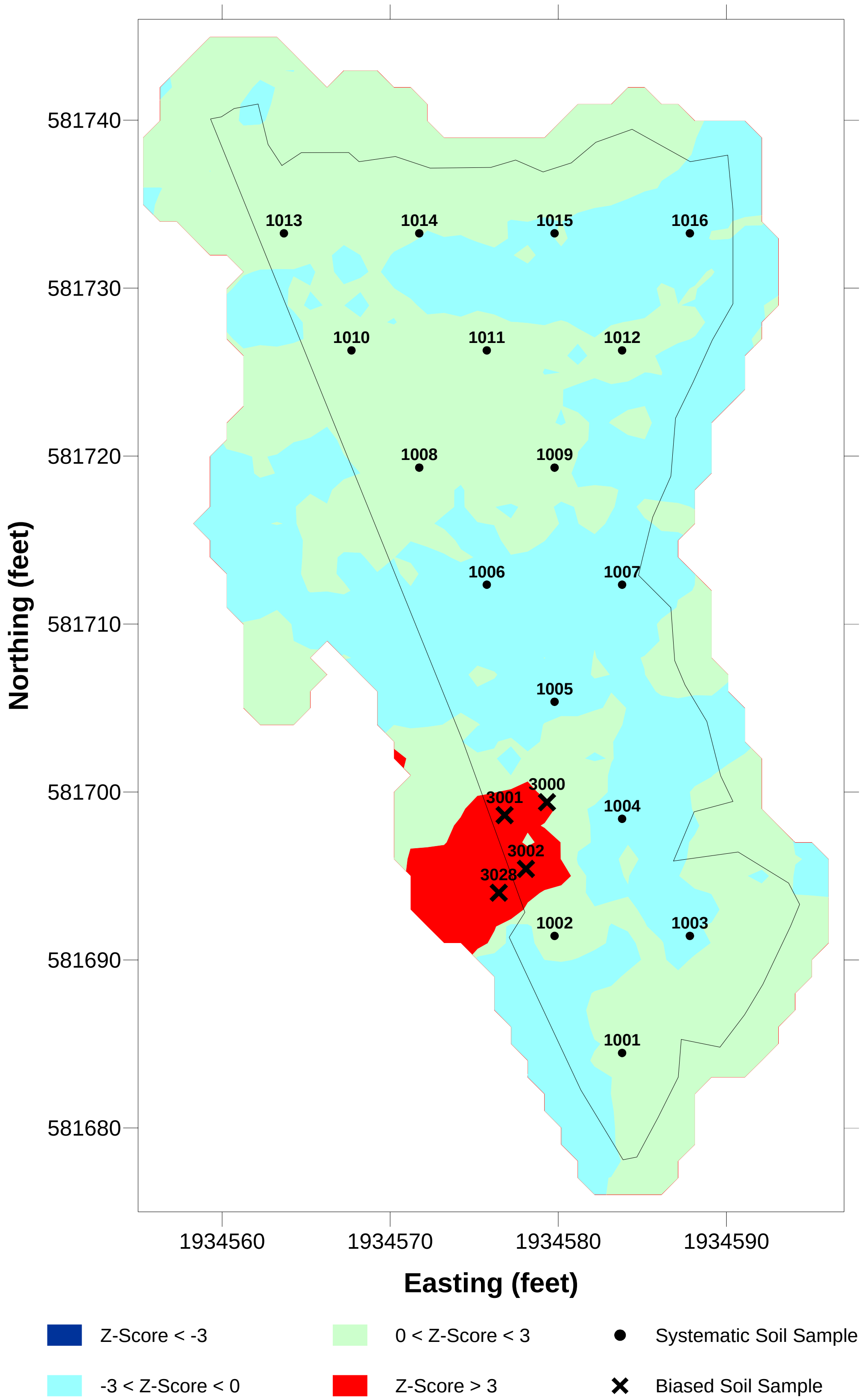


Figure 3.6 – Survey Unit 2 Z-Score Contour Map

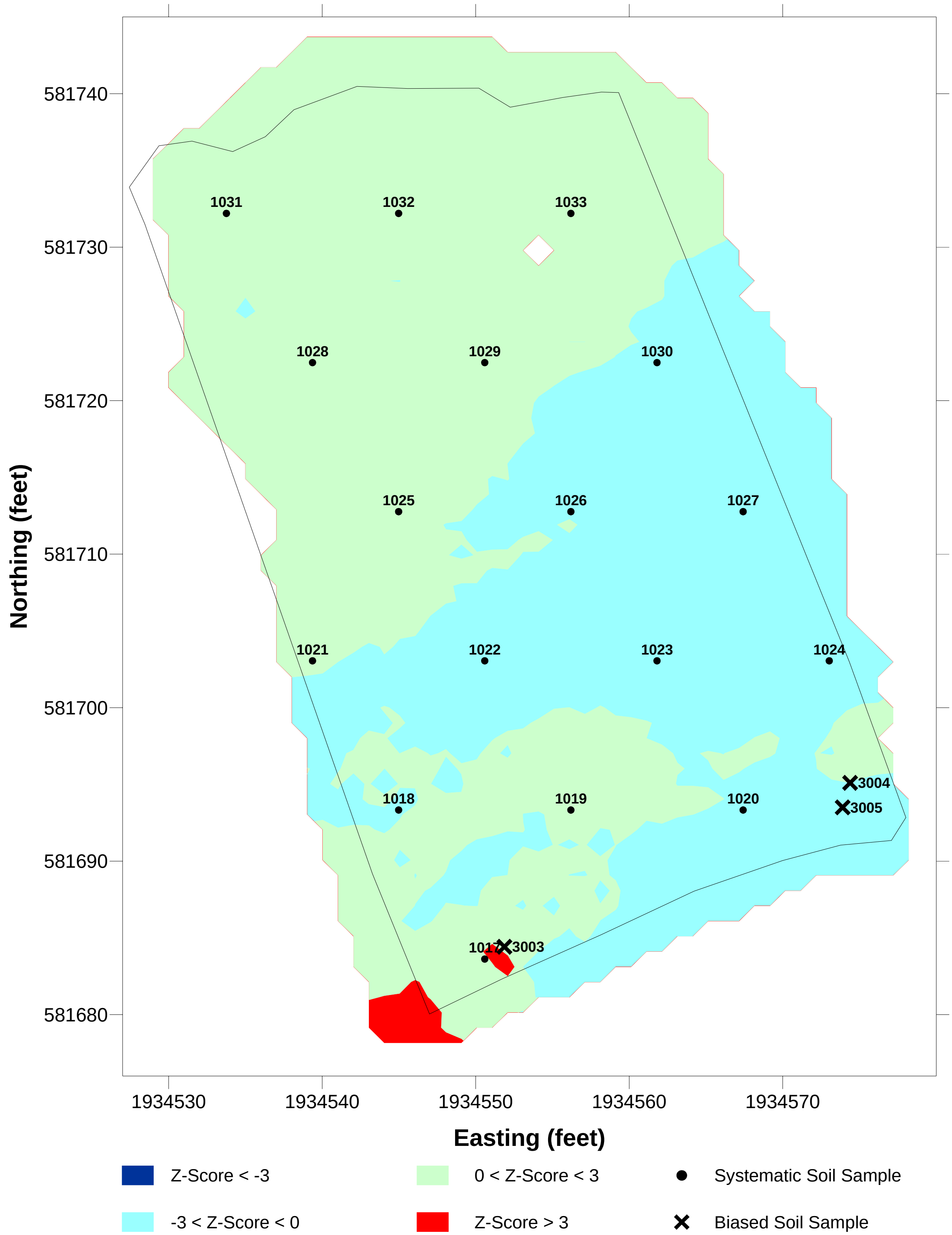


Figure 3.7 – Survey Unit 3 Z-Score Contour Map

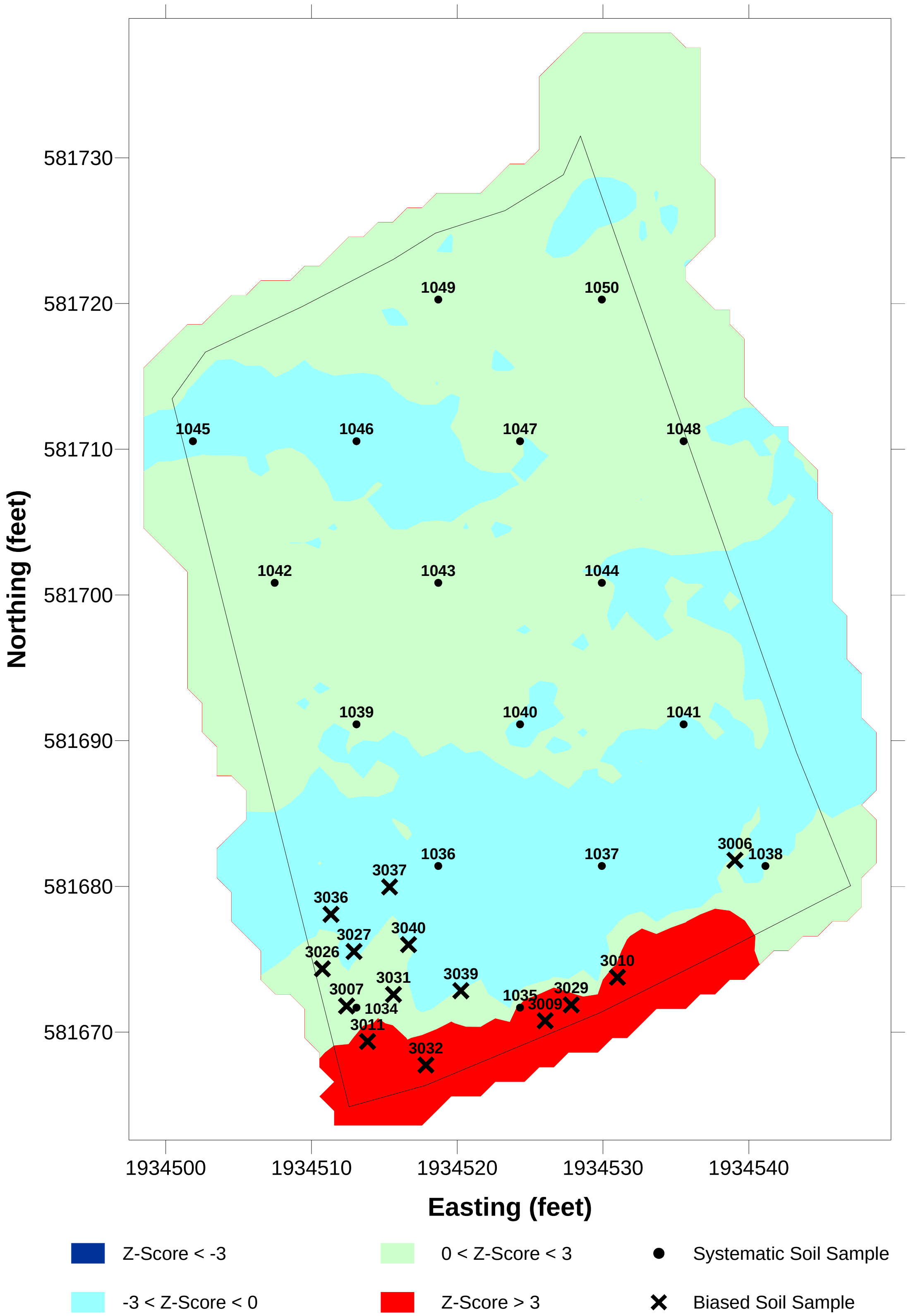


Figure 3.8 – Survey Unit 4 Z-Score Contour Map

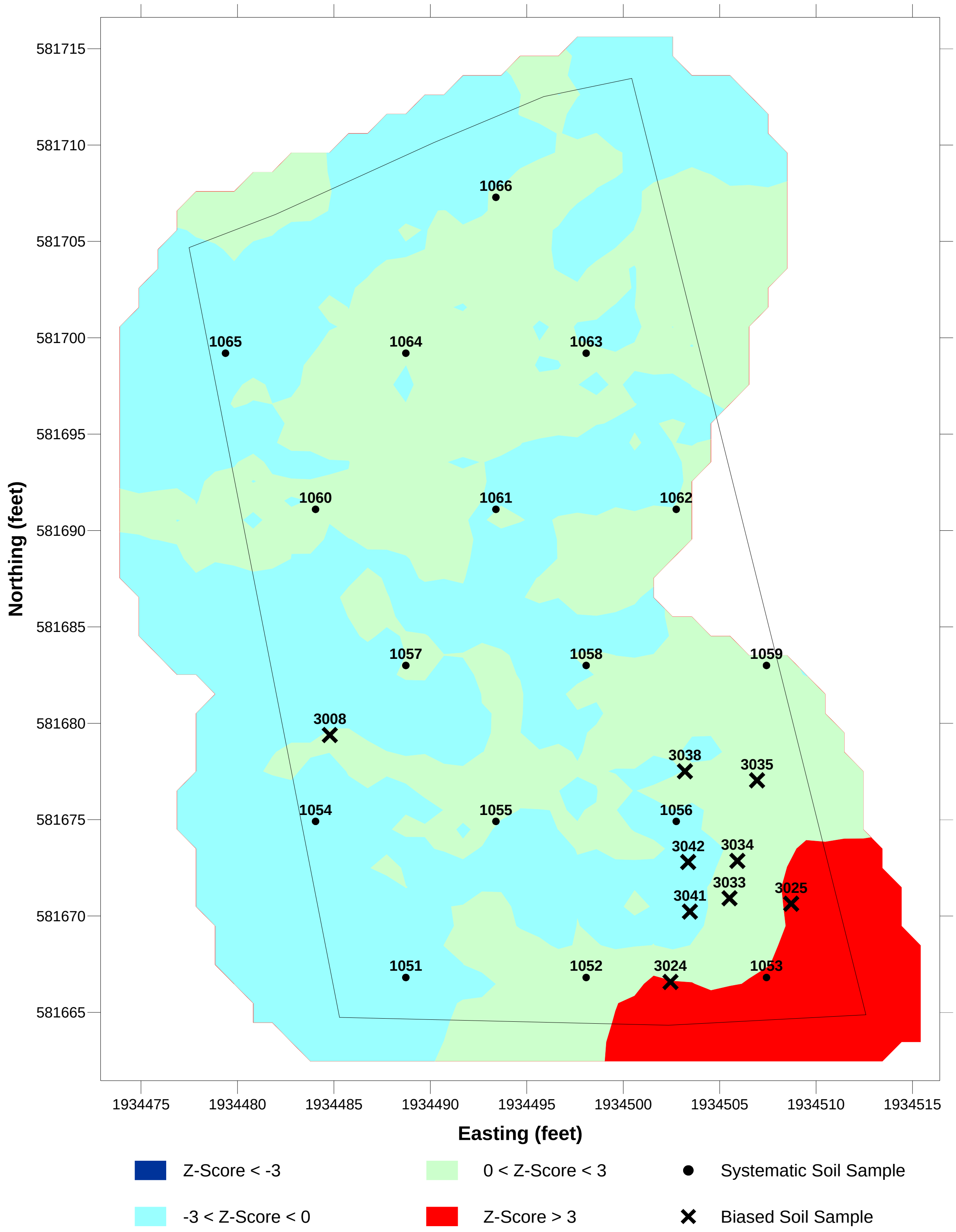


Figure 3.9 – Survey Unit 5 Z-Score Contour Map

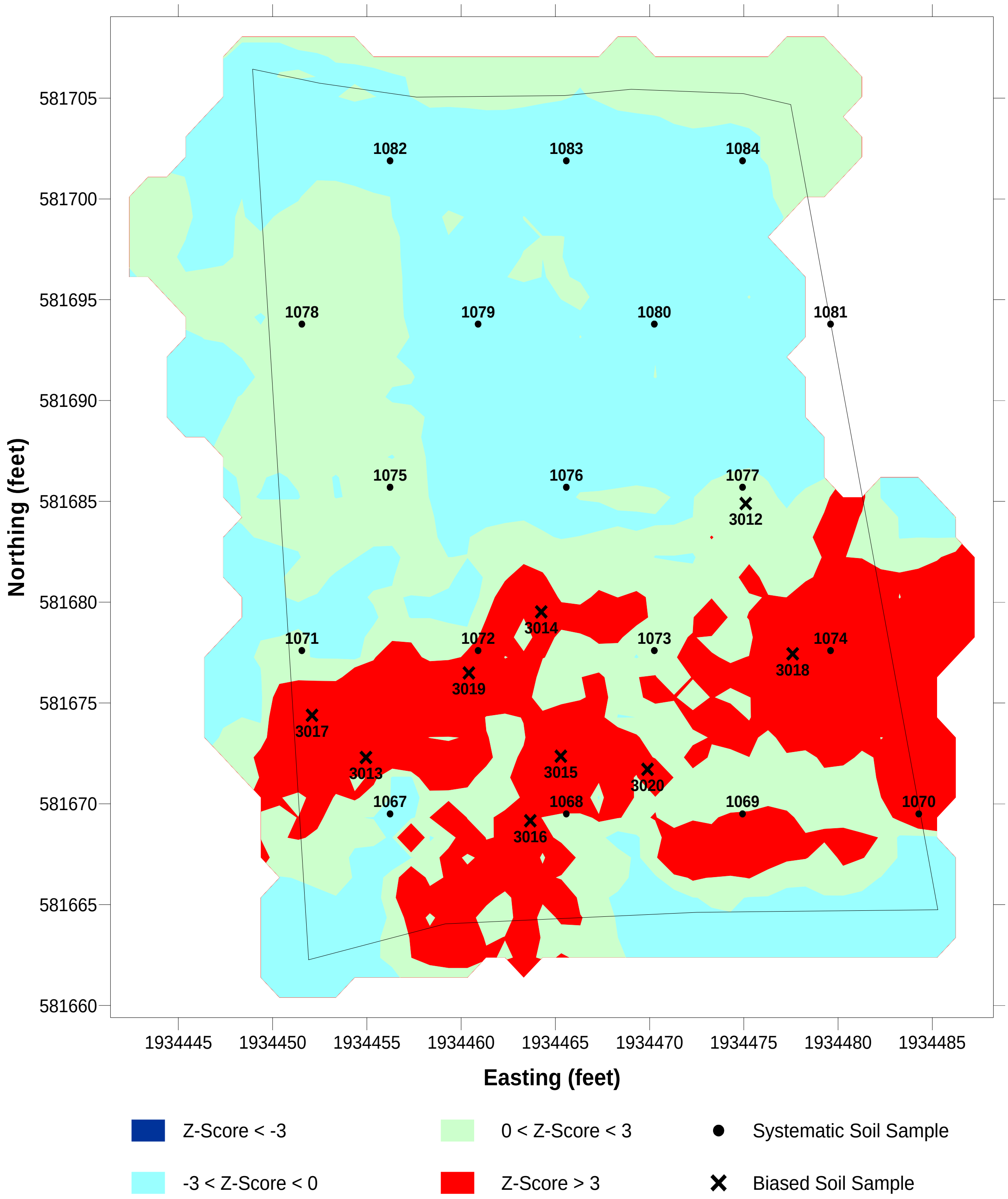


Figure 3.10 – Survey Unit 6 Z-Score Contour Map

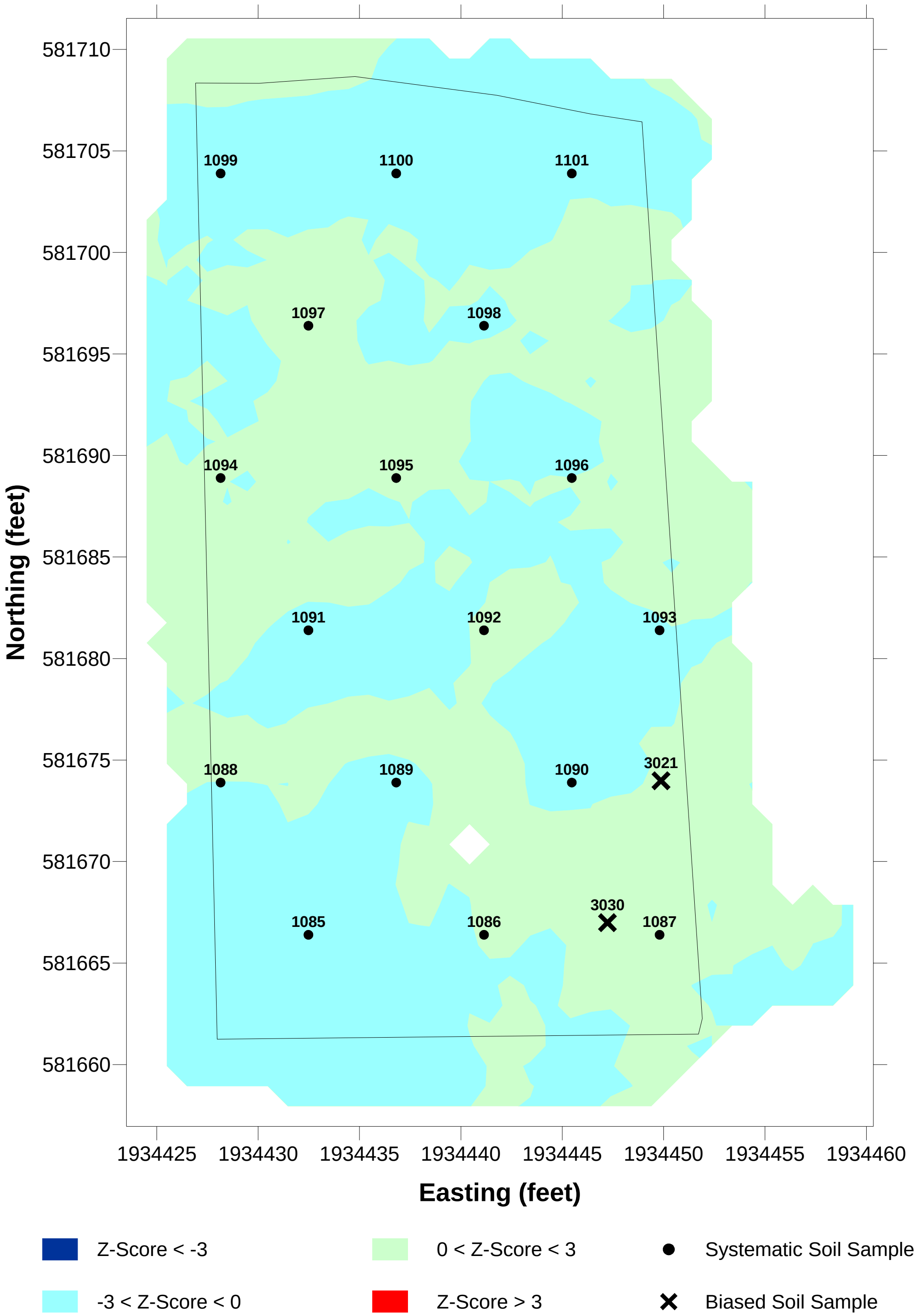


Figure 3.11 – Survey Unit 7 Z-Score Contour Map

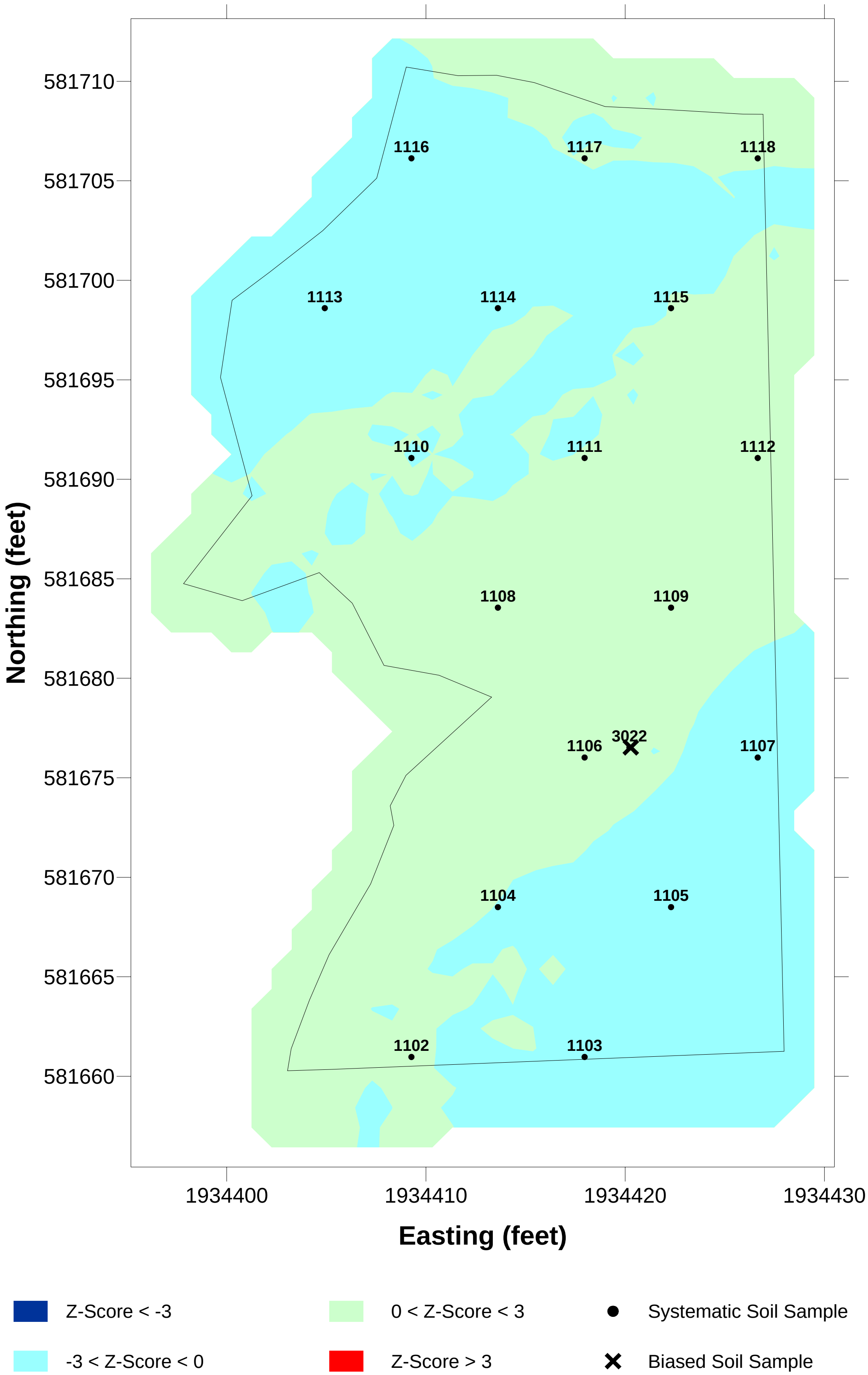
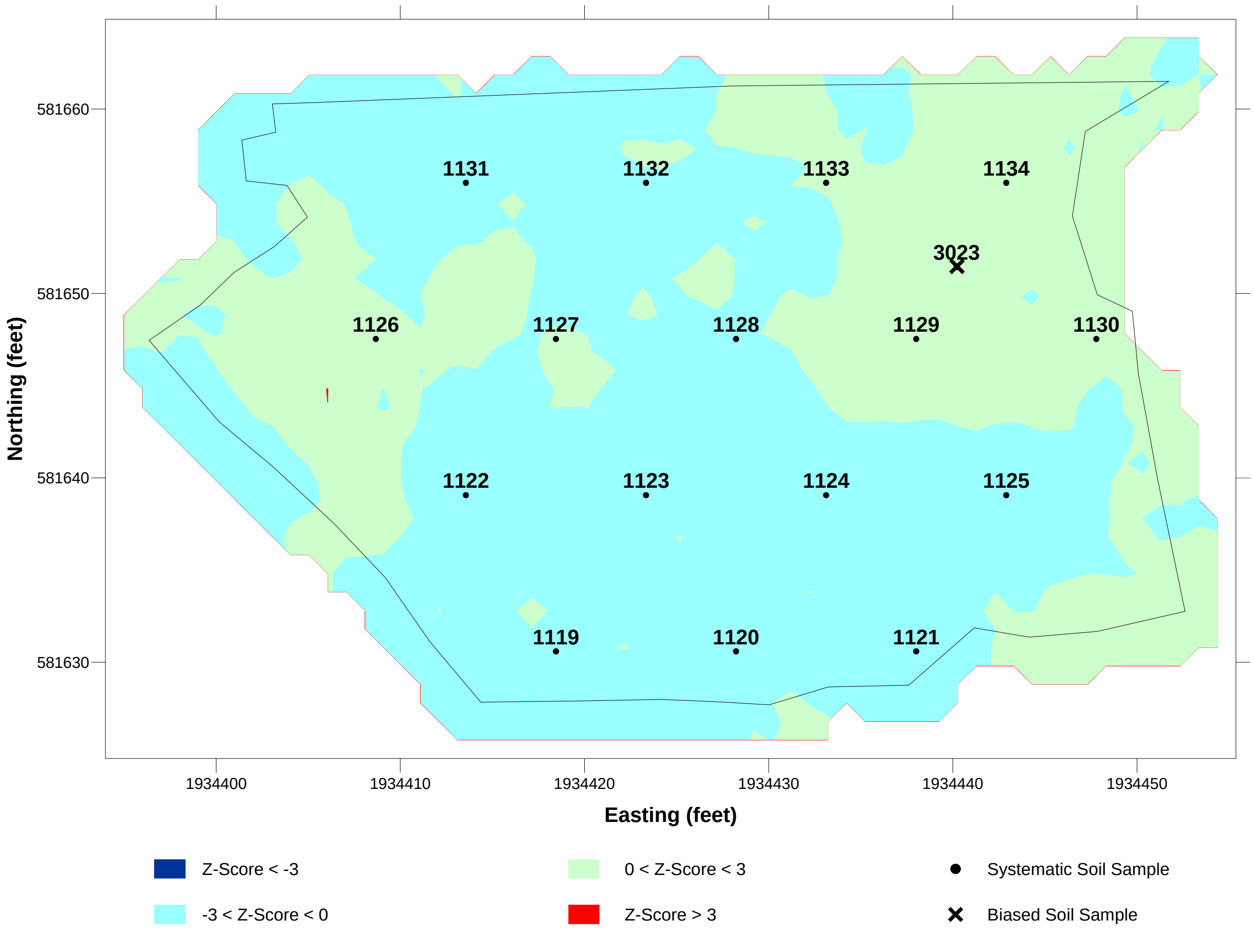


Figure 3.12 – Survey Unit 8 Z-Score Contour Map



3.4.2 On-site Laboratory Gamma Spectroscopy Analysis of Surface Soil Samples

Surface soil samples collected from random-start systematic and biased sample locations were analyzed at the on-site laboratory by gamma spectroscopy. The results of each sample were compared to the project action level of 7.15 pCi/g ^{137}Cs (the on-site laboratory routinely achieved an MDC of less than 0.1 pCi/g ^{137}Cs with a count time of 15 minutes). The results of four samples (sample locations 1034, 3011, 3025, and 3026) exceeded the project action level. Three of the sample locations are in Survey Unit 3; the fourth sample location is in Survey Unit 4.

Additional samples were collected from biased sample locations spaced around each sample location with the elevated results to determine the lateral extent of the radioactive contamination. These samples were analyzed and compared to the project action level. Where the results exceeded the project action level, additional samples were collected from biased sample locations spaced further from the original sample location with the elevated results. In general, the samples were spaced approximately 10 ft. from the initial and subsequent sample locations. GPS data were collected to document each biased sample location (northing and easting point). Sixteen samples were collected in this manner from Survey Units 3 and 4 and are shown in Figure 6.1 along with nearby random-start systematic sample locations. These 16 samples, in addition to the 27 biased samples originally collected, make for a total of 43 samples collected from biased sample locations.

3.5 Subsequent Implementation of Decision Rules

The off-site laboratory analysis of surface soil samples by gamma spectroscopy was used to confirm the results of on-site laboratory measurements used in decision rule implementation and to determine whether radionuclide-specific analysis for hard-to-detect radionuclides of concern would be performed.

3.5.1 Off-site Laboratory Confirmation of Real-Time Decision Rule Implementation

The off-site laboratory performed gamma spectroscopy analysis of the surface soil samples to confirm the results of on-site laboratory measurements. Table 3.2 lists those samples identified by the on-site laboratory to exceed the project action level for ^{137}Cs. The off-site laboratory identified the same soil samples as exceeding the project action level, thereby confirming the implementation of the decision rule based on the sample analysis results of the on-site laboratory.

3.5.2 Radionuclide-Specific Analyses for Other Activation Products

The gamma spectroscopy analysis performed by the off-site laboratory did not detect ^{60}Co above the MDC in any of the surface soil samples. Since ^{60}Co was not detected, radionuclide-specific analyses for other activation products ^{3}H, ^{55}Fe, ^{59}Ni, and ^{63}Ni were not performed.

Table 3.2 – On-site vs. Off-site Laboratory Results for ^{137}Cs Above Project Action Level

Survey Unit	*Sample ID*	*On-site Laboratory Result (pCi/g)*	*Off-site Laboratory Result (pCi/g)*
3	1034	18.9	23.5
	3011	16.3	16.1
	3026	9.00	7.38
4	3025	9.20	9.40

3.6 Summary of Decision Rule Implementation

A summary of the results of the implementation of the decision rules established in the survey design is presented in Table 3.3.

Table 3.3 – Summary of Decision Rule Implementation

Parameter of Interest	*Criteria*	*Action Taken*
Gross Gamma Walkover		
Presence of Contamination	Area with z-score greater than 3.0 is identified.	Twenty-five biased sample locations selected for sampling from areas with z-score greater than 3.0 in Survey Units 1 through 6.
	A gross gamma result is the highest result in a survey unit.	Highest gross gamma result selected for sampling as biased sample location in Survey Units 7 and 8 (no areas with z-score > 3.0)
Small Area of Elevated Activity – Highest and Biased Investigation		
Presence of Contamination	Gamma spectroscopy results for a surface soil sample do not exceed project action levels.	Results for 133 of 134 samples from random-start systematic sample locations and 25 of 27 samples from initial biased sample locations did not exceed the project action levels.
	Gamma spectroscopy results for a surface soil sample exceed project action levels.	Sixteen supplemental biased sample locations selected to determine lateral extent of area of elevated radioactivity.
Average Radionuclide Activity Concentration		
Average survey unit Radioactivity	The ^{137}Cs concentration for all systematic sample results from the on-site laboratory is less than 7.15 pCi/g in a survey unit.	Off-site laboratory analyses report random-start systematic samples below 7.15 pCi/g in all survey units but Survey Unit 3 (sample location 1034); MARSSIM statistical tests demonstrate survey units meet the release criteria.
	The ^{137}Cs concentration for any systematic sample results from the on-site laboratory exceeds 7.15 pCi/g in a survey unit.	On-site laboratory analysis reported a single systematic sample above 7.15 pCi/g, which revealed the small area of elevated activity in southern portion of Survey Units 3 and 4.
	A survey unit is uniformly contaminated	No survey unit identified as uniformly contaminated; therefore, no action taken.
	A small area of elevated activity is identified within a survey unit,	Option presented to and accepted by the Boeing project manager for additional investigation by surface soil sampling.
	The ^{60}Co concentration for any systematic sample results from the off-site laboratory exceed the MDC,	No ^{60}Co concentration exceeded MDC; therefore, no option presented to the Boeing project manager to perform analysis for the presence of hard-to-detect activation products.

4.0 SURVEY RESULTS

Four types of measurements were performed as part of the survey:

- Gross gamma walkover measurements,
- Gamma spectroscopy of surface soil samples,
- Alpha spectroscopy of surface soil samples, and
- Radionuclide-specific analyses for strontium-90 (^{90}Sr) and plutonium-241 (^{241}Pu).

These measurement techniques were selected based on the radionuclides of concern assuming surface soil as the media to be measured or sampled. Exposure rate measurements were also collected, but for health and safety purposes (see Section 3.2.3). The gross gamma walkover survey and on-site gamma spectroscopy of soil samples were used to provide near real-time feedback for confirming the presence and defining the nature and lateral extent of gamma-emitting radioactivity. Decision rule implementation using near real-time feedback is addressed in Section 3.4. The use of an on-site laboratory reduced the time required to analyze samples and provided near real-time analytical results. The off-site laboratory performed gamma spectroscopy and alpha spectrometry analyses of the soil samples. Radionuclide-specific analyses for ^{90}Sr and ^{241}Pu were also performed by the off-site laboratory to identify and measure these beta-emitting radionuclides of concern.

4.1 Data Quality Assessment

Survey data were verified authentic, appropriately documented, and technically defensible. Specifically, the following conclusions were made:

- The instruments used to collect the data were capable of detecting the radiation types and energies of interest at or below project action levels and/or the target MDCs.
- The calibration of the instruments used to collect the data was current and radioactive sources used for calibration were NIST traceable.
- Instrument response was checked before and, where required, after instrument use each day data were collected.
- The MDCs and the assumptions used to develop them were appropriate for the instruments and the survey methods used to collect the data.
- The survey methods used to collect the data were appropriate for the media and types of radiation being measured.
- The custody of samples collected for off-site laboratory analysis was tracked from the point of collection until final results were obtained.
- The survey data consist of qualified measurement results that are representative of the area of interest and collected as prescribed by the survey design.

4.2 Data Analyses by Radionuclide

Twenty-eight radionuclides were reported and/or detected above their respective MDCs. Summary statistics by radionuclide are provided in Table 4.1 below for both random-start systematic and biased samples. Results are reported as pCi/g dry weight with estimated total propagated measurement uncertainty and MDC in pCi/g dry weight. The complete off-site laboratory analyses results are found in Appendix B.

Table 4.1 – Summary Statistics by Radionuclide (includes Random and Biased Samples)

Radionuclide Measured	*Samples Reported*	*Samples w/Activity > MDC*	*Reported Concentration (pCi/g)*		
			Average	*Std Dev*	*Max*
Radionuclide Analysis by Gamma Spectroscopy					
^{22}Na	177	0	-0.000014	0.0370	0.0870
^{40}K	177	177	21.9	2.37	28.2
^{54}Mn	177	0	0.00461	0.0273	0.0650
^{60}Co	177	0	0.00498	0.0288	0.0760
^{134}Cs	177	0	0.00187	0.0354	0.110
^{137}Cs	177	109	0.915	2.49	23.5
^{152}Eu	177	0	-0.0243	0.276	0.620
^{154}Eu	177	0	0.0165	0.215	0.630
^{226}Ra[a]	177	177	0.866	0.208	1.45
^{232}Th[b]	161	161	1.19	0.261	2.09
Radionuclide Analysis by Alpha Spectroscopy					
^{228}Th	177	177	1.21	0.274	2.53
^{232}Th	177	177	1.17	0.280	2.36
^{234}U	177	177	1.02	0.778	9.60
$^{235/236}$U	177	81	0.0552	0.0655	0.730
^{238}U	177	177	0.893	0.666	8.60
^{238}Pu	177	1	0.00451	0.0151	0.103
$^{239/240}$Pu	177	5	0.00566	0.0127	0.116
^{241}Am	177	3	0.0105	0.0183	0.123
Radionuclide Analysis by Gas Proportional Beta					
^{90}Sr	177	51	0.510	2.13	28.2
Radionuclide Analysis by Liquid Scintillation					
^{241}Pu	177	0	-0.110	1.57	4.90

Note:
- a Results reported for ^{226}Ra by progeny ^{214}Bi.
- b Results reported for ^{232}Th by progeny ^{228}Ac

4.2.1 Gamma Spectroscopy Results

Surface soil samples were analyzed by gamma spectroscopy. The gamma spectroscopy analysis library included the radionuclides of concern and is included with reported data in Appendix B.

Four gamma-emitting radionuclides were detected above the MDC: ^{40}K, ^{137}Cs, ^{226}Ra (by progeny ^{214}Bi), and ^{232}Th (by progeny ^{228}Ac). Concentrations detected above the MDC of ^{40}K are consistent with expected background concentrations, as presented in *Historical Site Assessment of Area IV, Santa Susana Field Laboratory, Ventura County, California* (Sapere 2005); those for ^{232}Th are slightly higher. Both radionuclides are naturally occurring. Elevated concentrations of ^{137}Cs were also identified in Survey Units 3 and 4.

Four samples reported concentrations of ^{137}Cs above the project action level of 7.15 pCi/g (modified ^{137}Cs DCGL). These samples are listed in Table 4.2 below and their location is shown in Figure 6.1. The average concentration (0.915 pCi/g) is skewed by several relatively large outliers in the population. The difference between the average (0.915 pCi/g) and and the median (0.465 pCi/g) indicates the presence of outliers, resulting in the skewed distribution.

Table 4.2 – Sample Locations with ^{137}Cs Above Project Action Level

Survey Unit	*Sample Location*	*Concentration (pCi/g)*
3	1034	23.5
3	3011	16.1
4	3025	9.40
3	3026	7.38

The ^{226}Ra results by progeny ^{214}Bi reported expected background concentrations, while those based on the 186 keV photon peak reported concentrations several times higher. The 186 keV peak has a very low abundance, only 3.3%, and gamma spectroscopy cannot resolve the ^{226}Ra photon peak from the 185.7 keV photon peak of ^{235}U. To resolve this inconsistency, three samples reporting the highest ^{226}Ra concentrations based on the 186 keV photon peak were reanalyzed to investigate the potential for interferences from the presence of ^{235}U. The samples were sealed to allow ^{226}Ra progeny growth over a three-week period (sufficient time for the ^{226}Ra progeny to reach secular equilibrium) and analyzed by gamma spectroscopy. Table 4.3 compares the initial ^{226}Ra results (based on the 186 keV peak) to the ^{214}Bi progeny results from the reanalysis. Since the reanalysis was performed after secular equilibrium was established, the ^{214}Bi results from the reanalysis provide a more accurate estimate of the ^{226}Ra activity in these samples. Therefore, the ^{214}Bi results were used in the ^{226}Ra data analyses.

Table 4.3 – Sample Locations with ^{226}Ra Above DCGL

Survey Unit	*Sample Location*	*Sample Concentration (pCi/g)*	
		Initial Analysis of ^{226}Ra Based on the 186 keV Photon Peak	*Reanalysis of ^{214}Bi in Secular Equilibrium with ^{226}Ra*
4	1066	5.1 ± 2.0	0.89 ± 0.22
3	3006	7.1 ± 1.8	0.95 ± 0.20
5	3017	6.1 ± 2.0	1.5 ± 0.33

4.2.2 Alpha Spectrometry Results

Surface soil samples were analyzed by alpha spectrometry for thorium, uranium, and plutonium radionuclides. All of the samples reported ^{228}Th, ^{232}Th, ^{234}U, and ^{238}U above the MDC. Other radionuclides reporting concentrations above the MDC in one or more samples included $^{235/236}$U, ^{238}Pu, $^{239/240}$Pu, and ^{241}Am. Radionuclide concentrations detected above the MDC are consistent with expected background concentrations (Sapere 2005). No analyses were performed for ^{242}Pu, which was used as a tracer for off-site laboratory analysis.

4.2.3 Results of Radionuclide-Specific Analyses for ^{90}Sr and ^{241}Pu

Surface soil samples were analyzed by gas proportional beta analysis for ^{90}Sr and liquid scintillation analysis for ^{241}Pu. No samples reported ^{241}Pu above the MDC.

Approximately one-third of the samples reported ^{90}Sr concentrations above the MDC. The median concentration of ^{90}Sr is 0.220 pCi/g. The average concentration of 0.510 pCi/g is skewed by a single outlier of 28.1 pCi/g (sample location 3030) in Survey Unit 6 (see Figure 3.8). All other reported ^{90}Sr results detected above the MDC are less than 3.30 pCi/g. A review of the results reported from sample location 3030 does not reveal elevated concentrations of any other radionuclides.

4.2.4 Off-site Laboratory MDCs - Target vs. Achieved

Target MDC values, given in Table 4.4, were established in the RMHF Perimeter FSP (CABRERA 2005) and assumed a sample size of 500 grams and a count time of 120-300 minutes. MDCs for gamma-emitting radionuclides were based on achieving 10% of the ^{137}Cs project action level or less. The target MDC for ^{226}Ra was based on the 186 keV peak and the ^{232}Th MDC was based on ^{228}Ac.

Table 4.4 – Target vs. Achieved Off-site Laboratory MDCs

Radionuclide Measured	*No. of Samples w/Detected Activity*	*Target MDC (pCi/g)*	*Achieved MDC (pCi/g)*		
			Average	*Max*	*Min*
Radionuclide Analysis by Gamma Spectroscopy					
^{22}Na	0	0.5	0.130	0.180	0.0820
^{40}K	177	3	0.969	2.40	0.100
^{54}Mn	0	0.5	0.106	0.140	0.0580
^{60}Co	0	0.2	0.120	0.180	0.0630
^{134}Cs	0	0.3	0.0882	0.140	0.0390
^{137}Cs	109	0.1	0.121	0.240	0.0550
^{152}Eu	0	1	0.951	1.40	0.520
^{154}Eu	0	1.3	0.861	1.30	0.440
^{226}Ra[a]	177	5	0.337	0.680	0.140
^{232}Th[b]	161	1	0.360	0.910	0.190
Radionuclide Analysis by Alpha Spectroscopy					
^{228}Th	177	0.1	0.0695	0.120	0.0400
^{232}Th	177	0.1	0.0467	0.110	0.0200
^{234}U	177	0.1	0.0523	0.110	0.0100
$^{235/236}$U	81	0.1	0.0512	0.130	0.0160
^{238}U	177	0.1	0.0485	0.120	0.0200
^{238}Pu	1	0.1	0.0588	0.110	0.0200
$^{239/240}$Pu	5	0.1	0.0449	0.110	0.0190
^{241}Am	3	0.1	0.0632	0.130	0.0290
Radionuclide Analysis by Gas Proportional Beta					
^{90}Sr	51	1	0.400	0.720	0.200
Radionuclide Analysis by Liquid Scintillation					
^{241}Pu	0	20	4.02	8.00	2.20

Note:
- a Results reported for ^{226}Ra by progeny ^{214}Bi; target MDC based on ^{226}Ra by 186 keV photon peak.
- b Results reported for ^{232}Th by progeny ^{228}Ac; target MDC based on ^{232}Th by progeny ^{228}Ac.

4.3 Data Evaluation by Survey Unit

A total of 177 surface soil samples (excluding the nine duplicate surface soil samples collected for laboratory QC) were collected from 134 random-start systematic and 43 biased sample locations in eight survey units. The results of three samples indicated radionuclide concentrations above their respective DCGLs. The results of a fourth sample reported ^{137}Cs concentration above the project action level and caused additional sampling to be performed. Survey unit sampling information and summary ^{137}Cs and ^{90}Sr statistics are presented in Table 4.5.

Exploratory data analysis (EDA) was performed on the results of the off-site laboratory analysis of random-start systematic samples to identify radionuclide distribution trends and potential outliers. EDA included visual inspection of results using posting plots, cumulative frequency distributions, histograms, and calculation of statistical quantities including mean, median, standard deviation, and range. The statistical comparisons and graphical representations of the data by survey unit are found in Appendix A.

Table 4.5 – Survey Unit Sampling and Summary Statistics

Parameter	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***Site***
Number of Surface Soil Samples Collected									
Systematic	16	17	17	16	18	17	17	16	134
Biased	4	3	14	9	9	2	1	1	43
Total	20	20	31	25	27	19	18	17	177
> DCGL	0	0	2[a]	1	0	0	0	0	3
^{137}Cs Statistics – Random and Biased Samples									
Mean	0.250	0.263	2.56	1.39	0.469	0.252	0.103	1.07	0.915
Std Dev	0.249	0.218	5.05	2.30	0.873	0.297	0.104	1.63	2.49
Maximum	0.930	0.830	23.5	9.40	4.53	1.12	0.310	5.84	23.5
^{90}Sr Statistics – Random and Biased Samples									
Mean	0.149	0.615	0.540	0.461	0.180	1.75	0.174	0.318	0.510
Std Dev	0.116	0.724	0.435	0.496	0.279	6.39	0.0803	0.236	2.13
Maximum	0.440	3.29	1.53	1.56	1.43	28.1	0.360	0.850	28.1

Notes:

a Results of a third sample exceeded project action level of 7.15 pCi/g ^{137}Cs, but not the DCGL.

4.3.1 Survey Unit 1

Samples were collected from 16 random-start systematic sample locations in Survey Unit 1. The gross gamma walkover survey identified a cluster of small elevated areas (i.e., z-score above 3.0) near the southwest corner of the survey unit (see Figure 3.3). Samples were collected from four biased sample locations distributed in and around the cluster. None of the samples reported radionuclide concentrations above their respective DCGLs.

4.3.2 Survey Unit 2

Samples were collected from 17 random-start systematic sample locations in Survey Unit 2. The gross gamma walkover survey identified a cluster of small elevated areas in the southeast corner (adjacent to the cluster of elevated areas in Survey Unit 1) and a smaller cluster in the southwest corner of the survey unit (see Figure 3.4). Samples were collected from three biased sample locations distributed among the elevated areas. None of the samples reported radionuclide concentrations above their respective DCGLs.

4.3.3 Survey Unit 3

Samples were collected from 17 random-start systematic sample locations in Survey Unit 3. The gross gamma walkover survey identified elevated count rates in the southwest corner of the survey unit and extending along nearly the entire southern edge of the survey unit boundary (see Figure 3.5). The area, which is adjacent to the RMHF perimeter fence, was influenced by gamma shine from Building 4021, a radioactive waste treatment facility within the RMHF (see Figure 4.1). Initially, samples were collected from four biased sample locations. The sample results from one random-start systematic location (1034) and one biased sample location (3011) reported ^{137}Cs concentrations above the project action level of 7.15 pCi/g ^{137}Cs. Consequently, samples were collected from an additional 10 biased sample locations distributed around the two initial sample locations with elevated results. The sample results from biased sample location 3026 also reported ^{137}Cs above the project action level. See Table 4.2 for elevated ^{137}Cs results.

Figure 4.1 – Survey Unit 3/4 Are of Elevated ^{137}Cs Concentration (Looking West)

Though below their respective DCGLs, unusually high concentrations of ^{234}U and ^{238}U were reported at biased sample location 3006. The reported concentrations, 9.6 and 8.6 pCi/g respectively, are over two times higher than other sample locations.

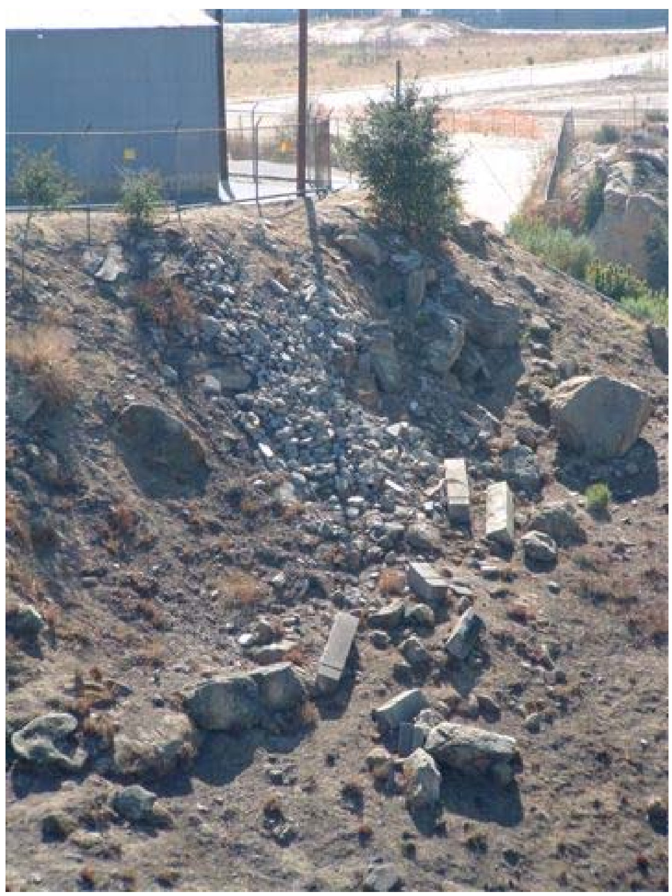
4.3.4 Survey Unit 4

Samples were collected from 16 random-start systematic sample locations in Survey Unit 4. The gross gamma walkover survey identified elevated count rates in the southeast corner of the survey unit that appears to be an extension of the elevated area identified in the southwest corner of Survey Unit 3 (see Figure 3.6). The area, which is adjacent to the RMHF perimeter fence, was influenced by gamma shine from Building 4021, a radioactive waste treatment facility within the RMHF (see Figure 4.1). A smaller elevated area was identified near the middle of the western edge of the survey unit, which is adjacent to the several large clustered elevated areas in the south half of Survey Unit 5 (see Figure 3.7). Initially, samples were collected from two biased sample locations in and around the smaller elevated area. None of the samples reported radionuclide concentrations above their respective DCGLs. However, sampling performed to define the nature and lateral extent of the radioactive contamination in Survey Unit 3 caused samples to be collected from seven additional biased sample locations. The sample results from one of those biased sample locations (3025) reported ^{137}Cs concentrations above the project action level. See Table 4.2 for elevated ^{137}Cs results.

4.3.5 Survey Unit 5

Samples were collected from 18 random-start systematic sample locations in Survey Unit 5. The gross gamma walkover survey identified elevated count rates in several relatively large areas in the southern half of Survey Unit 5 (see Figure 3.7). The area, shown in Figure 4.2 below, appears to be a concrete debris field. Samples were collected from nine biased sample locations distributed among the elevated areas. None of the samples reported radionuclide concentrations above their respective DCGLs.

Figure 4.2 – Debris Field in South Half of Survey Unit 5 (Looking Southwest)



4.3.6 Survey Unit 6

Samples were collected from 17 random-start systematic sample locations in Survey Unit 6. The gross gamma walkover survey identified a small elevated area on the eastern boundary near the southeast corner adjacent to the large clusters of elevated areas in the south half of Survey Unit 5 (see Figure 3.8). Samples were collected from two biased sample locations in and around the elevated area. None of the samples reported radionuclide concentrations above their respective DCGLs.

Though below its respective DCGL, an unusually high concentration of ^{90}Sr was reported at biased sample location 3030. The reported ^{90}Sr concentration of 28.1 pCi/g is over eight times higher than any that reported at any other sample location. A review of the results from sample location 3030 does not reveal elevated concentrations of any other radionuclides.

4.3.7 Survey Unit 7

Samples were collected from 17 random-start systematic sample locations in Survey Unit 7. The gross gamma walkover survey did not identify any elevated areas in the survey unit (see Figure 3.9). A sample was collected from a biased sample location at the point of the highest gross gamma results in the survey unit. None of the samples reported radionuclide concentrations above their respective DCGLs.

4.3.8 Survey Unit 8

Samples were collected from 16 random-start systematic sample locations in Survey Unit 8. The survey unit is traversed by an asphalt-lined drainage ditch (see Figure 4.3 below). The gross gamma walkover survey found elevated count rates along the entire ditch. No other areas were identified. Since the drainage ditch is outside the scope of the survey, no elevated areas remain in the survey unit (see Figure 3.10). A sample was collected from a biased sample location at the point of the highest gross gamma results in the survey unit. None of the samples reported radionuclide concentrations above their respective DCGLs.

Figure 4.3 – Asphalt-Lined Drainage Ditch in Survey Unit 8 (Looking West)

4.4 Statistical Test

The off-site laboratory analysis results for the random-start systematic surface soil samples were evaluated using the statistical tests in MARSSIM.

4.4.1 Sum-of-Fractions Calculations

Since there are multiple radionuclides of concern, the sum of fraction (SOF) was calculated for each sample by summing the concentration of each radionuclide of concern divided by its corresponding DCGL. The release criterion is met where the SOF is less than or equal to unity, as illustrated:

$$\frac{C_1}{DCGL_1} + \frac{C_2}{DCGL_2} + \ldots \frac{C_n}{DCGL_n} \leq 1$$

where:

C_n = Concentration of radionuclide n

$DCGL_n$ = DCGL for radionuclide n

SOF calculations do not include ^{40}K (see Section 2.3). They also do not include Ra, Th, and U radionuclides (see following section).

The results are shown in Table 4.6. Sample location 1034 in Survey Unit 3 was the only random-start systematic sample location to exceed unity. The radionuclide-specific DCGL for ^{137}Cs was exceeded at that sample location.

Table 4.6 – Sum of Fractions by Survey Unit

Survey Unit	***No. of Samples with SOF > 1***	***Survey Unit***	***No. of Samples with SOF > 1***
1	0	5	0
2	0	6	0
3	1	7	0
4	0	8	0

4.4.2 Sign Test

The Sign test was applied to the random-start systematic sample data. The Sign test assumes the data are independent random measurements and statistically independent. The Sign test is based on the hypothesis that the radionuclide concentration in the survey unit exceeds the DCGL. This is referred to as the null hypothesis. There must be sufficient survey data with radionuclide concentrations at or below the DCGL to reject the null hypothesis and conclude the radionuclide concentration in the survey unit does not exceed the DCGL. Normally, the Sign test is applied where the radionuclide of concern is not present in background. However, the Sign test may also be used if the radionuclide is present in background at a small fraction of the DCGL. In other words, background is considered insignificant. In this case, the background concentration of the radionuclide is included with the residual radioactivity (in other words, the entire amount is attributed to facility operations). Thus, the total radionuclide concentration was compared to the

DCGL. This option was used since it was expected that ignoring the background concentration would not affect the outcome of the statistical test. The advantage of ignoring a small background concentration is that no background reference area is needed.

The Sign test was performed by survey unit for the radionuclides of concern using the SOF calculation (see preceding section). It was also performed for individual Ra, Th, and U radionuclides of concern. This was done individually for these radionuclides because their DCGLs are based on DOE Applicable or Relevant and Appropriate Requirements (ARARs) and not on dose-based, RESRAD derived soil concentrations.

The results of the SOF and ARAR Sign tests are summarized below. The test statistic S+ is the number of samples where the SOF is less than unity or where the sample concentration is below the DCGL. The critical value, from MARSSIM Appendix I.3, is the minimum number of such samples needed to reject the null hypothesis. The results of the individual radionuclides are presented in Appendix A.

Table 4.7 – Survey Unit SOF and ARAR Sign Test Results

Statistical Test Parameter	***Survey Unit***							
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***
No. of Random Samples	16	17	17	16	18	17	17	16
Test Statistic S+	16	17	16[a]	16	18	17	17	16
Critical Value	11	12	12	11	12	12	12	11
Test Result	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass

Notes:

a Test statistic S+ is 17 for ARAR Sign Tests.

The decision error rates α and β were established by the RMHF Perimeter FSP (CABRERA 2005) at 0.05. Since the test statistic S+ is greater than the critical value, sufficient statistical evidence exists to reject the hypothesis that the radionuclide concentration in the survey unit exceeds the DCGL for all eight survey units.

4.4.3 Retrospective Power Analysis

A retrospective power analysis was performed as described in MARSSIM Appendix I.9. Normally it is performed only when the statistical test fails to reject the null hypothesis, since it demonstrates whether the number of samples collected provided sufficient statistical power to the test. Where the test concludes there is sufficient statistical power to reject the null hypothesis, the number of samples collected is moot. Basically, the power of the test, i.e., the probability of rejecting the null hypothesis, increases with increasing sample size and declines with increasing sampling variance. Where the statistical power is insufficient based on the number of samples or the size of the sample variance, additional samples may be collected and the test conducted using the larger sample population.

The utility of a retrospective power analysis is found in verifying a sufficient number of samples was collected in the event a statistical test is not performed. The statistical test provides no useful information when all of the sample results are less than the DCGL. The probability of rejecting the null hypothesis is always 100% and the question regarding whether a sufficient number of samples were collected will remain unless answered by a power analysis.

Calculation assumptions used to construct the power analysis, given in Table 4.8, are from the RMHF Perimeter FSP (CABRERA 2005) and are based on the concentration of ^{137}Cs in the surface soil.

Table 4.8 - Retrospective Power Analysis Assumptions

Parameter	*Value*
Modifed ^{137}Cs DCGL	7.15 pCi/g
Assumed Standard Deviation (σ)	2.5 pCi/g
Lower Bound of Gray Region (LBGR)	2.5 pCi/g
False Positive Decision Error (α)	0.05
False Negative Decision Error (β)	0.05

The results, shown in Table 4.9, indicate that, with the exception of Survey Unit 3, the number of samples collected per survey unit was greater than the minimum number required to assure sufficient statistical power to the test. This is expected since the actual standard deviations, with the exception of Survey Unit 3, are less than the standard deviation assumed in the survey design upon which the number of samples to be collected was based. For Survey Unit 3, the power analysis identifies 40 samples as required to provide sufficient statistical power. This information would be useful in the survey design, but is presently moot since one or more samples exceeded the DCGL and the Sign test was performed, concluding there was sufficient statistical power to reject the null hypothesis.

Table 4.9 – Retrospective Power Analysis by Survey Unit

Analysis Parameter	*Survey Unit*							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Actual Std Dev (pCi/g)	0.27	0.23	5.7	1.5	1.0	0.27	0.11	1.7
Required Number	13	13	40	13	13	13	13	14
Number Collected	16	17	17	16	18	17	17	16
Result	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Pass

Survey Unit 3 is the only survey unit that reported an SOF greater than unity at one sample location, which was due to an elevated concentration of ^{137}Cs. The result of the Sign test was to reject the null hypothesis in spite of the single sample with an activity concentration greater than the DCGL. A subjective review of the data confirms this conclusion. Of the 17 samples collected, 15 samples reported ^{137}Cs concentrations less than 1.4 pCi/g. One sample reported 5.6 pCi/g and the highest sample reported 23.5 pCi/g. Provided the assumptions underlying the Sign test were not violated, it is clear that there is a very high probability that the average concentration across the survey unit is less than the modified ^{137}Cs DCGL of 7.15 pCi/g.

A retrospective power curve for Survey Unit 3 is shown in Figure 4.4. The curve shows the probability of rejecting the null hypothesis versus the concentration of radioactivity. Due to the large sample variance (standard deviation of 5.7 pCi/g), a relatively large number of samples (40) is required to demonstrate the average concentration is approximately 3 pCi/g in order to have a 95% probability of rejecting the null hypothesis.

Power curves, such as that shown in Figure 4.5 for the SOF in Survey Unit 8, provide little useful information for survey units where all of the sample results are significantly less than the DCGL and/or the sample variance is small relative to the DCGL. In these cases, as few as 13 samples are required with a 100% probability of rejecting the null hypothesis with an average concentration as high as two or more times the LBGR.

Figure 4.4 – Retrospective Power Curve for ^{137}Cs in Survey Unit 3

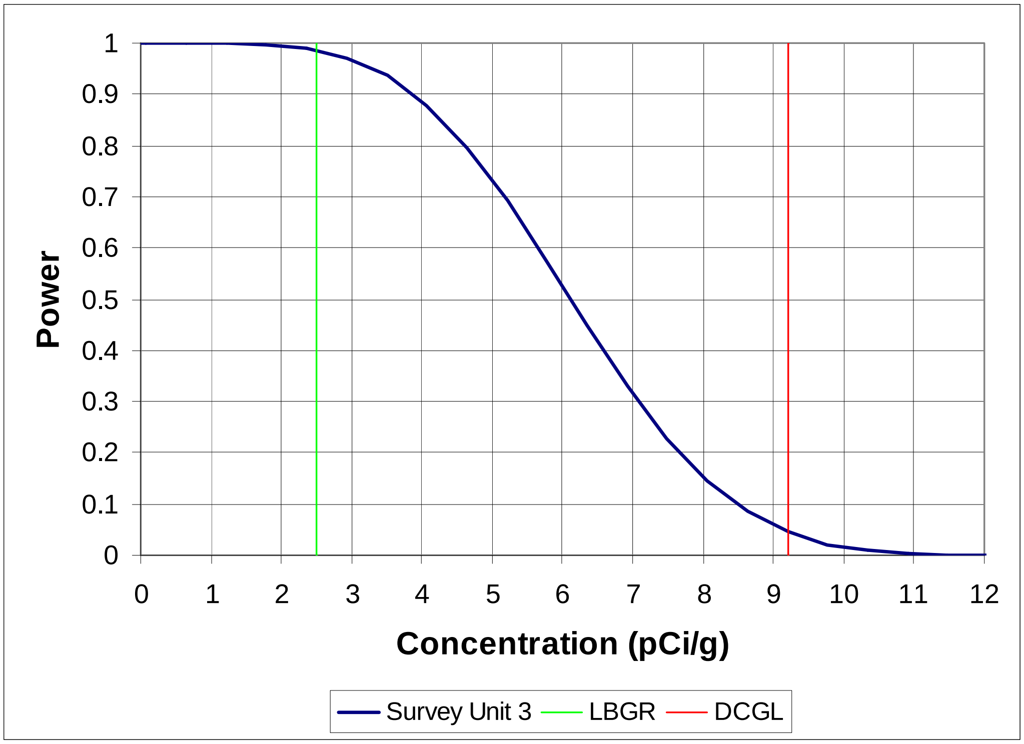
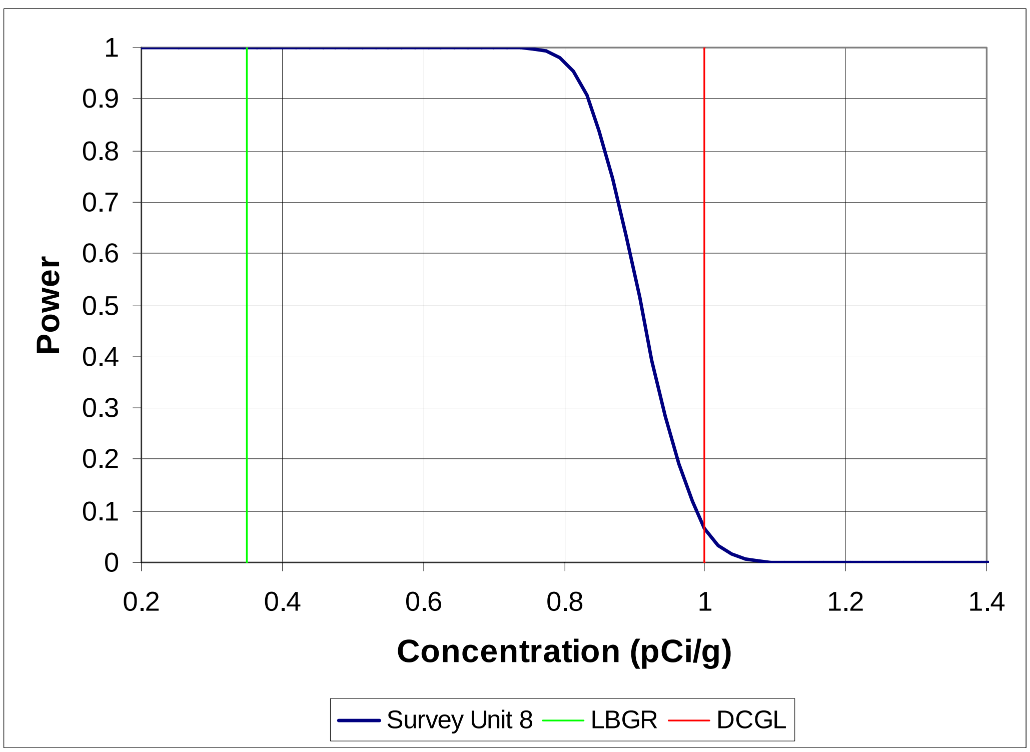


Figure 4.5 – Retrospective Power Curve for SOF in Survey Unit 8



5.0 QUALITY CONTROL

Portable and laboratory instrumentation capable of detecting the radiation types and energies of interest were selected, calibrated, and maintained for survey data collection (see Appendix C). QC measures, discussed in the following sections, were implemented throughout the project to ensure data met known and suitable data quality criteria such as precision, accuracy, representativeness, comparability, and completeness.

Variables related to data precision and accuracy were monitored by field and laboratory response checks designed to monitor the performance of the instrumentation used to collect the data. Duplicate analyses were performed by the on-site and off-site laboratories and compared to verify key decision parameters (i.e., decision rule implementation).

The representativeness of the data was ensured by adherence to the survey design set forth in the RMHF Perimeter FSP (CABRERA 2005) and the use of standardized data collection methods and techniques established in written procedures. Surveyors were trained on these documents, copies of which were maintained on-site and referenced as needed.

Routine monitoring of surveyor performance and environmental factors was performed to ensure data comparability. Where comparability issues were identified (e.g., change in ambient radiation levels due to movement of radioactive waste at the RMHF), measures were instituted to avoid future problems. Data were reviewed and, where necessary, discarded and re-collected.

The type and quantity of collected data were reviewed against survey design requirements to ensure data completeness.

5.1 Portable Instrumentation

The following table lists the types of portable instrumentation.

Table 5.1 – Portable Instrumentation

Instrument	*Detector*	*Detector Type*	*Radiation Type*
Ludlum Model 2221	Ludlum Model 44-20	3” x 3” NaI Scintillation	gamma
Ludlum Model 2360	Ludlum Model 43-93	Alpha/Beta Scintillation	alpha, beta
Ludlum Model 2241	Ludlum Model 44-9	G-M	beta, gamma
Ludlum Model 2929	Ludlum Model 43-10-1	Scintillation	alpha, beta
Bicron MicroRem	n/a	Scintillation	gamma
Trimble TDC1 GPS	n/a	n/a	n/a

5.1.1 Calibration and Maintenance

Survey instruments were calibrated for the radiation types and energies of interest. Radionuclide mixture ratios and varying energies were accounted for during calibration by using a calibration source with a conservative average energy as compared to the weighted average energy of the radionuclide mixture. Radioactive sources used for calibration purposes are traceable to the National Institute of Standards and Technology (NIST).

5.1.2 Instrument Response

Survey instrument response was checked before and after instrument use each day. A check source was used that emitted the same type of radiation (alpha, beta, or gamma) as the radiation being measured and that gave a similar instrument response. The response check was performed using a specified source-detector alignment that could easily be repeated. Results within 20% of the expected values were considered acceptable. Expected values were calculated as the average of at least 10 initial checks of the instrument. If the instrument failed its response check, it was not used until the problem was resolved.

The Trimble GPS units were checked daily against a calibration point. The calibration point was selected upon commencement of fieldwork and consisted of a stable site feature unlikely to move during the project (e.g., fencepost, pavement intersection, etc.). Prior to initial GPS use, ten static positional readings were obtained at the calibration point. From these positional readings, a mean position was determined. Thereafter, the GPS units were checked against the calibration point at least daily. The acceptance criterion for GPS daily checks was within one meter of the calibration point, as calculated using the Pythagorean theorem. GPS units exhibiting positional error in excess of one meter were not used until corrective action was taken.

5.1.3 Minimum Detectable Concentration

A minimum detectable concentration (MDC) was determined using the methods described in MARSSIM for instruments used to perform the gross gamma walkover survey, as described in Section 5.1 of the RMHF Perimeter FSP (CABRERA 2005). The scan speed, distance above ground surface, radionuclides of concern, and detector characteristics were considered in the calculation. The ^{137}Cs scan MDC for the gross gamma walkover survey was estimated to be 3.73 pCi/g. This value is approximately 50% of the project action level (i.e., the ^{137}Cs modified DCGL). To evaluate whether the MDC was achieved, surface soil sample results for ^{137}Cs were reviewed. Fourteen sample locations (both random-start systematic and biased) were identified with ^{137}Cs concentrations above 3.73 pCi/g. Of these, 11 of the 14 sample locations were identified by gross gamma walkover survey data as areas of elevated radioactivity, as shown in Table 5.2.

Table 5.2 – Sample Locations Above 3.73 pCi/g ^{137}Cs

Survey Unit	*Sample Location*	*^{137}Cs Soil Concentration*	*Elevated Area?*
3	1034	23.5	Yes
	1040	5.58	No
	3011	16.1	Yes
	3026	7.38	Yes
	3027	3.91	Yes
	3031	4.03	Yes
	3040	3.82	Yes
4	1053	5.94	Yes
	3024	3.98	Yes
	3025	9.40	Yes
	3034	4.65	Yes
5	1068	4.53	Yes
8	1130	4.45	No
8	1126	5.84	No

Biased sample locations selected based on the gross gamma walkover survey data reported surface soil ^{137}Cs concentrations as low as 0.058 pCi/g (sample location 3002 in Survey Unit 2).

No surface soil samples reported ^{137}Cs concentrations above the project action level in areas not previously identified by gross gamma walkover survey data.

5.2 Laboratory Instrumentation

Three types of quality control (QC) samples were analyzed to evaluate laboratory performance:

- Replicate samples to evaluate the effectiveness of sample preparation techniques.
- Laboratory control samples to evaluate the accuracy of the measurements.
- Reagent blank samples to evaluate the potential for laboratory contamination.

One of each type of sample was analyzed for QC purposes for every 20 project samples analyzed. The on-site laboratory performed replicate and reagent blank samples, but the laboratory control samples were replaced with check sources to prevent the possibility of site contamination resulting from damage to a laboratory control sample.

The following table presents a summary of the laboratory QC analyses, their frequency, and the acceptance criteria that were used.

Table 5.3 – Laboratory Quality Control

QC Check	***Minimum Frequency***	***Acceptance Criteria***
Gamma Spectroscopy (On-site and Off-site Laboratory)		
Resolution Check	Daily	Within 3 standard deviations of the established full width at half maximum
Energy Calibration	Daily for one low energy peak and one high energy peak	Within 3 standard deviations of the established peak centroid
Detector Background	Weekly	1,200 minutes
LCS or Check Source	One per 20 samples (5%) or one per batch, whichever is more frequent	Recovery 70-130% of expected value
Reagent Blank	One per 20 samples (5%) or one per batch, whichever is more frequent	Less than or equal to the MDC
Duplicates	One blind duplicate per survey unit, and one duplicate count per 20 samples (5%) or one per batch, whichever is more frequent	Relative percent difference (RPD) less than or equal to 20%
Off-site Laboratory (Alpha Spectrometry, Gas Proportional, Liquid Scintillation)		
LCS	One per 20 samples (5%) or one per batch, whichever is more frequent	Recovery 70-130% of expected value
Reagent Blank	One per 20 samples (5%) or one per batch, whichever is more frequent	Less than or equal to the MDC
Duplicates	One blind duplicate per survey unit, and one duplicate count per 20 samples (5%) or one per batch, whichever is more frequent	RPD less than or equal to 20%

5.2.1 Off-site Laboratory Duplicate Analyses

The off-site laboratory performed both blind analysis of duplicate samples and duplicate sample counts. Duplicate samples were collected at nine sample locations. The samples were collected at the same time, but were not mixed or otherwise homogenized. The results of the blind analysis of the duplicate samples are shown in Table 5.4. Six of the nine analyses passed the RPD criteria. The RPD criteria and its application are explained in the table footnotes. The inhomogeneity of the samples collected, the variability present in background concentrations, and the relatively low counting statistics are contributors to the three failures. With the variability inherent in the blind field duplication process, the results are considered acceptable.

Table 5.4 – RPD Analysis of Off-site Laboratory Duplicate Sample Analyses

Sample Location	*Radio-nuclide*	*Analytical Results (pCi/gram)* [(1, 2)]		*RPD (%)*[(3)]	*2σ Error (%)*[(4)]	*Pass?*[(5)]
		Duplicate	*Initial*			
1001	^{137}Cs	0.55 ± 0.14	0.56 ± 0.15	2	18	Yes
1017	^{137}Cs	0.29 ± 0.11	0.83 ± 0.17	96	18	No
1050	^{137}Cs	-0.020 ± 0.065	0.0080 ± 0.059	467	732	Yes
1059	^{137}Cs	0.99 ± 0.18	1.9 ± 0.31	63	33	No
1078	^{137}Cs	0.13 ± 0.098	0.12 ± 0.093	5	54	Yes
1101	^{137}Cs	0.011 ± 0.077	-0.024 ± 0.068	538	790	Yes
1111	^{137}Cs	0.12 ± 0.090	0.12 ± 0.094	3	54	Yes
1117	^{137}Cs	0.59 ± 0.16	0.035 ± 0.052	178	27	No
3024	^{137}Cs	3.2 ± 0.42	4.0 ± 0.55	23	10	Yes

Notes:
(1) Errors reported at the 95% confidence level.
(2) Minimum detectable activity concentrations (MDCs) reported at the 95% confidence level.
(3) RPD is equal to the absolute value of the difference of the duplicate and initial results multiplied by 100 and divided by the average of the two results.
(4) 2σ Error is equal to 0.5 times the square root of the sum of the duplicate counting error squared and the initial counting error squared, all divided by the average of the summed counting errors.
(5) The RPD is considered acceptable if it is less than or equal to 20% plus the 2σ counting error.

Duplicate counts were performed by the off-site laboratory in each of 10 sample lots. The results of the duplicate counts are shown in Table 5.5. Eight of the nine duplicate counts passed RPD criteria. The single failure was due to low counting statistics. The sample contained less than 0.03 pCi/g ^{137}Cs, and the MDC for that set of duplicate counts was 0.12 pCi/g ^{137}Cs. Therefore, the results are considered acceptable.

Table 5.5 – RPD Analysis of Off-site Laboratory Duplicate Count Results

Sample Location	*Radio-nuclide*	*Analytical Results (pCi/gram)* [1, 2]						*RPD (%)* [3]	*2σ Error (%)* [4]	*Pass?* [5]
		Duplicate			*Initial*					
1001-D	^{137}Cs	0.56	±	0.13	0.55	±	0.14	2	17	Yes
1006	^{137}Cs	0.091	±	0.071	0.091	±	0.066	<1	53	Yes
1017	^{137}Cs	0.98	±	0.19	0.83	±	0.17	16	14	Yes
1048	^{137}Cs	0.13	±	0.086	0.16	±	0.12	21	51	Yes
1066	^{137}Cs	0.16	±	0.12	0.29	±	0.13	56	39	Yes
1078	^{137}Cs	0.15	±	0.087	0.12	±	0.093	22	47	Yes
3016	^{137}Cs	1.41	±	0.24	1.27	±	0.21	10	12	Yes
1101	^{137}Cs	0.026	±	0.064	-0.024	±	0.068	3640	934	No
1114	^{137}Cs	-0.015	±	0.068	-0.014	±	0.060	8	302	Yes
1121	^{137}Cs	0.33	±	0.12	0.34	±	0.10	3	23	Yes

Notes:
(1) Errors reported at the 95% confidence level.
(2) Minimum detectable activity concentrations (MDCs) reported at the 95% confidence level.
(3) RPD is equal to the absolute value of the difference of the duplicate and initial results multiplied by 100 and divided by the average of the two results.
(4) 2σ Error is equal to 0.5 times the square root of the sum of the duplicate counting error squared and the initial counting error squared, all divided by the average of the summed duplicate and initial results.
(5) The RPD is considered acceptable if it is less than or equal to 20% plus the 2σ counting error.

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6.0 SUMMARY AND CONCLUSIONS

The general objectives of the survey were to provide sufficient information to:

- Confirm whether one or more radionuclides of concern exceed the project action levels in areas with known or suspected radioactive contamination.
- Define the nature and lateral extent of areas (i.e., areas of surface soil) where radionuclide concentrations exceed the project action levels.
- Verify assumptions used to develop the survey design.
- Delineate areas where no radionuclide concentrations exceed the project action levels and support recommendation for unrestricted release.

6.1 Presence of Radioactive Contamination

The presence of radioactive concentration (i.e., concentrations of one or more radionuclides above their respective DCGLs) was identified in a relatively small area in the southwest corner of Survey Unit 3 extending into adjoining southeast corner of Survey Unit 4, as shown in Figure 6.1. The results from three sample locations (1034, 3011, and 3025) indicated ^{137}Cs concentrations above its DCGL of 9.20 pCi/g.

6.2 Nature and Lateral Extent of Radioactive Contamination

The predominant radioactive contaminant is ^{137}Cs. The lateral extent of the radioactive contamination is a relatively small area (less than 100 square feet), enclosed by the solid rectangle in Figure 6.1. The area of radioactive contamination is surrounded by a larger area, enclosed by the polygon in Figure 6.1, where the surface soil concentration of ^{137}Cs exceeds 4 pCi/g.

6.3 Verification of Survey Design Assumptions

The survey was designed as a graded approach for thorough characterization with the intensity of a Class 1 MARSSIM final status survey. The gross gamma walkover survey was based on the assumption that gamma-emitters were indicative of potential small areas of elevated concentrations of radionuclides of concern. Biased sampling confirmed that the gross gamma walkover survey found elevated gamma-emitters below the ^{137}Cs DCGL. Off-site laboratory analysis did not identify any non-gamma emitting radionuclides of concern above their DCGLs. The random-start systematic sampling approach to survey homogeneous or wide spread contamination was successful in locating the radioactively contaminated area in Survey Units 3 and 4. The real-time field application of gamma spectroscopy allowed feed back for design optimization.

6.4 Areas Where Data Support Recommendation for Unrestricted Release

The data collected in Survey Units 1, 2, 5, 6, 7, and 8 are sufficient to support a recommendation for unrestricted release. Further dose assessment (or remediation) is required to support a recommendation for unrestricted release for the radioactively contaminated area identified in Survey Units 3 and 4. However, the data collected from those two survey units outside the area of contamination is sufficient to release the balance of Survey Units 3 and 4.

Figure 6.1 – Radioactively Contaminated Area

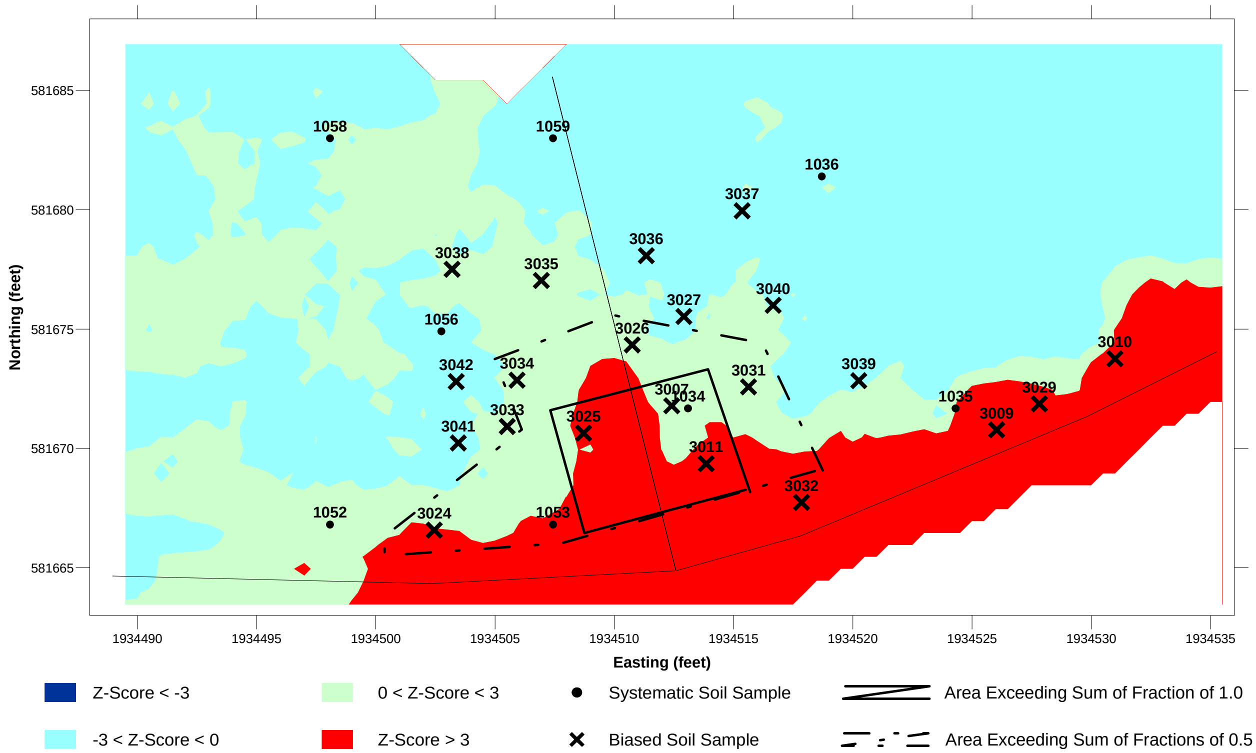

Table 6.1 – ^{137}Cs Concentrations In and Around Radioactively Contaminated Area

Sample Location	*pCi/g*	*Sample Location*	*pCi/g*	*Sample Location*	*pCi/g*	*Sample Location*	*pCi/g*
1034	23.5	3007	2.39	3027	3.91	3036	2.16
1035	0.430	3009	0.0720	3029	0.700	3037	3.12
1036	0.400	3010	0.460	3031	4.03	3038	0.450
1052	0.159	3011	16.1	3032	0.384	3039	0.500
1053	5.94	3024	3.98	3033	1.06	3040	3.82
1056	1.42	3025	9.40	3034	4.65	3041	0.114
1059	1.89	3026	7.38	3035	2.41	3042	0.500

7.0 RECOMMENDATIONS

Based on the results and conclusions of this report, CABRERA makes the following recommendations:

- Release Survey Units 1, 2, 5, 6, 7, and 8 for unrestricted use.
- Perform further investigation to support the release of the radioactively contaminated area in Survey Units 3 and 4 to unrestricted use. As an alternative to meet ALARA considerations for future site use, consider remediating and resurveying the radioactively contaminated area identified in Survey Units 3 and 4. This could be accomplished with a contamination-controlled excavation and buffer zone to limit the area requiring resurvey.
- Contingent upon the delineation of the remediated area and buffer zone, release the balance of Survey Units 3 and 4 to unrestricted use.

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8.0 REFERENCES

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EPA 2000a. *Multi Agency Radiation Survey and Site Investigation Manual (MARSSIM)*, 402-R-97-016, Revision 1, United States Environmental Protection Agency, August 2000.

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Appendix A

Data Analysis, Statistical Comparisons, and Graphical Representations

This appendix contains the data analyses of the off-site laboratory results of the random-start systematic and biased surface soil samples. Data analyses and statistical comparisons are presented in four Microsoft® Excel data files:

Off-site Lab Data Analysis by Radionuclide (184 pages)
Off-site Data Lab Analysis – ARAR Sign Test (41 pages)
Off-site Lab Data Analysis – Random Only (158 pages)
Off-site Lab Data Analysis – SOF Sign Test (74 pages)

Graphical representations of the data are found in three Microsoft® Word files:

CFD Graphs by Radionuclide (20 pages)
CFD Graphs by SU (160 pages)
Power Curves by SU (55 pages)

Graphical information was obtained from two unformatted Microsoft® Excel data files:

Raw Data Statistics and Tables
Sample Power Curves

Appendix B

Gross Gamma Walkover and On-site/ Off-site Laboratory Analysis Data

This appendix contains the collected survey data organized by type of data.

Gross Gamma Walkover Survey Data

Gross gamma walkover data are organized by survey unit and presented in eight Microsoft® Excel data files (1,447 pages). Each data file contains the easting, northing, and recorded count rate information along with the relative background population statistics for the "low" and "high" data set.

Off-site Laboratory Data

Off-site laboratory analysis results were reported in 10 sample lots. The reports are in Adobe® Acrobat® .pdf format (505 pages total) and corresponding electronic data files in comma-delimited format (unformatted), which can be viewed using Microsoft® Excel software. The off-site laboratory electronic data have been combined into a single Microsoft® Excel data file. The GPS coordinates for each sample location and the four-digit sample ID assigned by CABRERA field personnel have been added to the Microsoft® Excel data file. Laboratory QC and other supplemental data (e.g., laboratory name, matrix, date and time of sample collection, date of sample analysis) have been removed and minor formatting changes made to improve readability (148 pages). Laboratory QC data have been removed and placed in a separate file in Appendix C.

The laboratory analysis report (141 pages) and electronic data file (unformatted) for four samples (1066, 3006, 3017, and 3030) that were reanalyzed for ^{226}Ra by in-growth are presented in a separate Microsoft® Excel data file (1 page) and are not included with the combined off-site laboratory data. Formatting and other changes were made to the data file as described above.

On-site Laboratory Data

On-site laboratory analysis reports are organized by survey unit for each sample analyzed and may be viewed using Microsoft® Wordpad or other ASCII text viewing/editing software (1593 pages). The on-site laboratory data for each survey unit have been combined into a single electronic data file in comma-delimited format (unformatted), which can be viewed using Microsoft® Excel software. In addition, the on-site laboratory electronic data have been combined into a single Microsoft® Excel data file (60 pages).

Appendix C

Quality Control

This appendix contains portable and on-site laboratory instrument QC data and worksheets and off-site laboratory QC data analysis results. Instrument calibration certificates and QAF graphs are in Adobe® Acrobat® .pdf format

Calibration Certificates and QAF (22 pages)
88 keV centroid (1 page)
88 keV cps (1 page)
88 keV FWHM (1 page)
1332 keV centroid (1 page)
1332 keV cps (1 page)
1332 keV FWHM (1 page)

Instrument inventory and QC worksheets and off-site laboratory data are presented in nine Microsoft® Excel data files.

Bicron MicroRem QC Worksheet (unformatted)
Ludlum 2221 Gamma QC Worksheet (unformatted)
Ludlum 2360 Alpha Beta QC Worksheet (unformatted)
Ludlum 2929 Alpha Beta Counting and Smear Worksheet (unformatted)
Ludlum 2929 Alpha Beta Instrument Efficiency (unformatted)
Off-site Lab Duplicate Data Analysis (6 pages)
Off-site Lab QC Raw Data (unformatted)
SSFL Instrument Inventory
Trimble GPS QC Worksheet